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An economic analysis of alternative environmental and resource policies for controlling soil loss and sedimentation from agriculture

David John Walker
Iowa State University

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An economic analysis of alternative environmental
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David John Walker

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CHAPTER I. INTRODUCTION

Soil erosion and the resulting sediment load in surface water has been recognized in the United States for more than 40 years as an environmental and resource problem.[1] With the growing demand for U.S. agricultural commodities from domestic and foreign sources, erosion control is becoming increasingly important. The projected increases in world population through the year 2000 would require an estimated two-fold increase in food production [73]. If the rising trend in per capita consumption continues in countries with rising incomes, even greater increases in production will be necessary. These needs may not be met if agricultural lands in the U.S. and the rest of the world are depleted by soil erosion. Furthermore, the water quality objectives specified in the Water Pollution Control Act Amendments of 1972 [105] are not likely to be achieved unless soil erosion is controlled [10]. This study specifies and examines selected policy alternatives for erosion and sediment control.

Already the growing demand for food and fiber has been felt in the U.S. In response to rising agricultural prices, farmers in the United States have increased the acreage planted in crops by 35 million since 1970 to a total 370 million acres in 1976 [27]. While the 1976 cropland acreage does not represent a record plow-up since even greater acreages were cropped in some years during the 1940's and 1950's, the 1976

[1]The U.S. Soil Conservation Service was formed in 1935 out of concern over soil erosion.

acreage is the highest in 18 years [36]. Furthermore, some former cropland is now paved with highways and parking lots or is sprouting housing developments rather than food stuffs. Since 1945, 45 million acres of land have been converted to highways, urban development, and other special uses [102].

Even so, in 1976 U.S. agriculture was not yet bumping up against constraints on the amount of arable cropland. In a 1975 survey, the Soil Conservation Service reported that the U.S. had 111 million acres of land not in crops which could be readily converted to crop production [99]. In 1976 about 15 million acres of that land was brought under cultivation, leaving approximately 96 million acres that could still be converted. It is becoming obvious however, that if a doubling of output is desired, that additional production will not be met by bringing into cultivation vast amounts of new land in the U.S. Instead, the productivity of existing cropland must be nurtured and increased.

In spite of this need to enhance soil productivity, farmers are planting crops without adequately protecting the soil from erosion. Professor John F. Timmons of Iowa State University reported the results of a study in Western Iowa which showed that soil losses in that area had increased 22% between 1957 and 1974 as farmers plowed up pastures in an effort to increase corn and soybean production by 20% [63]. Besides fouling surface waters with suspended sediment, soil erosion strips topsoil and nutrients from agricultural lands and diminishes their ability to produce crops. In the past, farmers have attempted to compensate for the diminished productivity of their land by applying more fertilizers.

A shortage of energy has increased the cost of manufacturing fertilizer, limiting the feasibility of this remedy. Moreover, some of the eroded soil constituents, like organic matter, cannot be easily replenished. In effect, farmers appear to be "mining" the soil's productivity in response to higher crop prices. Apparently, the desire to maximize short-term profits has taken precedence over the longer term advantages of conserving the soil. One solution might be to implement policies which enhance the short-term profitability of soil-conserving production practices.

Recent projections of high levels of export demand for U.S. agricultural commodities [106] suggest that the productive capacity of U.S. agriculture will be under even greater strain by 1985 than it has been during the past few years. These mounting pressures from demand could result in production methods that further deplete the agricultural productivity of the soil as well as pose serious consequences for environmental quality.

As existing cropland is cultivated more intensively and as new land is brought under cultivation to meet the projected demands for food, soil erosion losses may be expected to increase. Continued agricultural production with unchecked soil erosion could seriously diminish the future yield from the land at a time when the nation will be seeking increased yields. These increasing soil losses, in conjunction with the more intensive use of agricultural chemicals, would also add to the pollution of the nation's water supplies. It is essential to anticipate the nature and extent of these threats to agricultural productivity and to environmental quality and to be prepared with policy alternatives for dealing with the problems. One fact illuminated in the light of our recent experience with increased agricultural production, is the need for improved erosion control in order to avoid further damage to our agricultural resource base and to preserve the quality of our surface waters.

Study Objectives

Earlier studies have attempted to assess the existing magnitude of soil loss from agricultural lands: Wadleigh in 1968 [110], Beasley in 1972 [11], and the National Research Council Committee on Agriculture and the Environment in 1974 [66]. Wade [109] in his 1975 linear programming analysis and Cory's [26] econometric forecast in 1977 attempt to project these soil losses into the future under alternative situations. Two earlier studies at Iowa State University have endeavored to assess the cost of achieving varying degrees of control over soil loss and sediment in surface water, Seay [81] in 1970 and Jacobs [51] in 1972. The Jacobs study, was updated by Webb [111] in 1977. While some refinements have been made, the methodology developed by Seay is the basis for the linear programming model used in this present study.

This study attempts to go beyond an assessment of the costs associated with the imposition of water quality constraints on an agricultural production model in that it seeks to evaluate some specific policy options for reducing soil loss and sedimentation by means of a linear programming simulation model. The focus of this report is on policy analysis at the river basin level. Specifically, the Nishnabotna River Basin, which is part of the Missouri River Drainage area in Southwest Iowa, is the subject area. Data for the river basin are available from county data series and are, therefore, fairly disaggregated and more specific than data compiled at the state or national level. The greater degree of specificity in the data allows more precise evaluation of policy impacts.

The specific objectives of this study are to:

1. Develop and document a model for investigating remedial policies to the double-edged problem of soil loss and sediment pollution;
2. Apply the model in a specified river basin to evaluate selected environmental and resource policies for reducing soil loss and sediment pollution under three price scenarios;
3. Identify further research needs.

The policy alternatives to be investigated in this research include: (1) ban on fall moldboard plowing, (2) ban against straight-row cultivation on slopes, (3) soil loss limit of 5 tons per acre, (4) tax based on soil loss per acre, (5) subsidy to encourage contour farming, and (6) subsidy to encourage the adoption of minimum tillage. Various combinations of these policies are also considered. Of particular interest in the course of this analysis are the consequences of these policies on (1) soil loss within the river basin, (2) net farm income, (3) crop production levels, (4) agricultural contribution to stream sediment load, and (5) the farm operator's choice of technology and land use.

Organization of Report

Chapter I introduces the problem area and outlines the specific objectives of the research covered in this report. Chapter II assesses the extent of the problem, explores the mechanics of soil loss and transport, and presents some remedial policy options. Chapter III discusses the analytical method for policy simulation and introduces the linear programming model. Chapter IV and Chapter V document the development of the economic and physical data sets for the river basin to which the model was applied. Chapter VI analyzes the results of the policy simulations. Chapter VII includes a summary and presents the conclusions of the research.

CHAPTER II. SOIL EROSION AND ASSOCIATED ENVIRONMENTAL PROBLEMS WITH REMEDIAL POLICY OPTIONS

Nature and Extent of Soil Loss

Soil erosion is a natural process. Potentially erosive forces were at work on the land long before inhabited by man. In the natural state however, much of the land was protected with a heavy cover of native vegetation. Under Mother Nature's stewardship the rate of soil formation usually exceeded the rate of soil loss in most regions. The same is not true under man's stewardship of the land.

Through his use of the land, man exposes the soil surface to the erosive forces of nature with the result that the soil is stripped away by wind and water. According to one estimate [73, p. 150] at least a third of the topsoil on U.S. croplands has been lost in the last 200 years. The dominant form of soil loss is from water runoff which delivers approximately 4 billion tons of sediment per year to surface waterways in the United States [66]. While three-fourths of the sediment originates from agricultural lands [96], other sources include logging, channel scouring, strip mining, construction sites, and urban stormwater runoff. Wind erosion, although generally less of a problem, can be severe particularly in semi-arid regions. Wind erosion is not considered in this research because of the difficulties in modeling that erosion process. This study concentrates on soil loss due to water erosion on agricultural land.

Just as erosion is an ongoing process on agricultural lands, so is the process of soil formation. While this rate of formation varies with climate and vegetation, it has been estimated [73, p. 150] that, under normal agricultural conditions, 1 inch of new soil would be formed in 100 years or a rate of about 1.5 tons of topsoil formed per acre per year. Compared to the average annual rate of soil loss from agricultural lands of 12 tons per acre [110], it is clear that agricultural production is depleting its resource base. With a net annual rate for soil loss of approximately 10 tons per acre, roughly one inch of topsoil is lost on the average every 15 years.[1]

Even before erosion reaches the point where the topsoil has been stripped from a field, the cumulative effect of erosion is evident in reduced crop yield from the land [86]. The reduced yields are partly a consequence of the thinning mantle of topsoil which contains essential nutrients. The loss of nutrients is more than proportional to the loss of topsoil, suggesting that the erosion process is selective. The run-off water more readily removes nitrogen, phosphorous, potassium, and organic matter than it removes the soil particles themselves [9, p. 306]. Tests of eroded sediment show that the concentrations of essential nutrients and organic matter are higher than in the original soil [57]. The selective loss of nutrients means poorer quality crops and lower yields. As erosion exposes the subsoil to cultivation, yields decrease for another reason. The subsoil generally has a poorer structure than topsoil so it becomes more difficult to prepare a suitable seedbed to

[1]One acre-inch of topsoil weighs approximately 150 tons [15].

the detriment of germination and yields.

Severely eroded soil suffers from moisture deficiency. Subsoil, because it does not contain as much organic matter as topsoil, is less permeable to water infiltration. Therefore, runoff is greater and moisture storage in the soil decreases. With less moisture in the soil available for crops, yields again suffer.

Often erosion is accompanied by gullying in the field. The formation of deep, wide gullies directly removes some land from cultivation and that loss increases as the gully advances. Also, by dividing the field into small segments which are difficult to farm, gullies reduce the productivity in agriculture [11, p. 17].

Nature and Extent of Sedimentation

The process of soil erosion presents, actually, a double-edged problem. Besides the lost productivity, soil erosion from farmland results in sediment pollution. As used in this report sediment pollution refers to the introduction of suspended particulate matter from cropland into surface waters by means of water runoff from agricultural land. As mentioned earlier, about three-fourths of the sediment in surface waters originates from agricultural lands. The suspended silt in runoff, which degrades the quality of surface waters, is the largest single pollutant of the nation's waterways [22, p. 151]. The suspended solids delivered to waterways by surface runoff amount to more than 700 times the load from sewage by weight according to one estimate [96]. The high turbidity of silt-laden water screens out sunlight and kills fish and other aquatic life. In addition, deposited sediment blocks road culverts, clogs navigational channels, and fills reservoirs thereby diminishing water storage and the degree of flood control. Sediment-laden water entering an impoundment behind an hydro-electric dam, reduces the storage capacity of the impoundment and hence the electrical generating capacity and also produces rapid wear on the turbine blades from abrasion [11, p. 19].

The suspended sediment also facilitates the contamination of water from chemicals by serving as a transport agent for the chemical pollutants. If nitrogen and phosphorous from fertilizer are present in the soil during erosion, chemical ions of these nutrients will be removed from the field attached to the surface of the eroding soil particles in a process called adsorption [45, p. 25]. When the transporting soil and chemicals reach a watercourse the chemicals may enter solution in the water or be deposited in high concentrations with the sediment.

The annual cost of all these sediment damages in the United States has been estimated at $500 million [72, p. 150]. The cost of dredging sediment from rivers and harbors alone amounts to $250 million annually [73, p. 150]. Since three-fourths of the stream sediment load originates from agricultural land, controlling soil erosion in agriculture will go a long way toward controlling sediment pollution.

Mechanics of Soil Erosion and Transport

In order to deal effectively with the dual problem of soil loss and sediment pollution, the mechanics of erosion and sediment transport must be understood. Soil erosion as a process involves the detachment of soil particles from the soil structure and the transport of the particles to another location. The energy for this process is provided by water as it falls toward the earth in the form of raindrops and as it flows over the land's surface. The process of erosion can actually be viewed as four subprocesses: soil detachment by rainfall, transport by rainfall, detachment by runoff, and transport by runoff [55, p. 8].

Sheet erosion

The type of erosion which takes place is often described according to the pattern in which soil movement from these erosive forces occurs. Sheet erosion refers to the fairly uniform removal of soil across the soil surface, and results from raindrop splash and generalized surface runoff. Since raindrops strike the surface with high velocity, they possess considerable energy. The impact of the raindrop breaks soil granules into smaller particles. The primary effect of rainfall is the detachment of soil particles but the splash action may carry these small particles several feet through the air. On sloped land there will be a general movement of the soil down the slope from the rain-splash. Therefore, rainfall also has transport capability. As pores in the soil structure begin to fill with water and small soil particles, the water infiltration rate for the soil decreases.[1] When the rainfall rate exceeds the infiltration rate, surface runoff begins. The runoff occurs initially as the movement of a shallow sheet of water overland. The detachment and transport from this shallow generalized water flow and the detachment and transport from raindrop impact constitute sheet erosion. Since soil loss is uniform, sheet erosion may go unnoticed.

Rill erosion

Rill erosion occurs when the runoff begins to concentrate along paths of least resistance. The erosive force of the flow eventually exceeds the inherent resistance of the soil structure to detachment and rill erosion begins forming rather small but definite channels or rills. The detachment and transport by runoff are the primary forces behind rill erosion. The appearance of a myriad of rills on the surface of the soil attests to soil loss through this type of erosion. These rills are so shallow that they are obliterated by normal tillage operations. Therefore, the cumulative effects of rill erosion can be easily overlooked.

Gully and channel erosion

As rill erosion progresses it can turn into gully erosion. The process of gully advance is more complex than rill erosion. The soil loss associated with an advancing gully can be due to the scouring action of flowing water, falling water in plunge-pools, and wet-dry and/or freeze-

[1]The process whereby small soil particles detached by rain-splash fill pores in the soil structure is called sealing. When the surface dries it appears crusted. With the soil surface sealed, the water infiltration rate is reduced and runoff increases, eventually causing an acceleration in rill erosion and gully erosion.

thaw cycles which result in the sloughing of the gully banks. Channel erosion is similar to gully erosion except that the flow of runoff water persists longer in the channel following a rainfall. In some rivers and streams the flow is continuous.

Transport of eroded soil

Sediment transport refers to the complex system of surface hydraulics which delivers detached soil materials from one location to another. The primary transport vehicle is streamflow. Large material rolls or bumps along the bottom of the stream and is sometimes called the bed load. Smaller but still coarse material is suspended in the stream flow by the turbulence of the moving water and is highly concentrated near the stream bed. Finer material is also transported in suspension with the flowing water but generally is distributed uniformly throughout the stream depth. Roughly 85% to 95% of the sediment yield is carried as suspended load [55]. Since water quality is most directly associated with the concentration of suspended solids, the suspended sediment load is of more interest to this research than bed load. Suspended sediment concentrations in U.S. rivers typically range from 200 to 50,000 mg/liter with occasional concentration as high as 600,000 mg/liter [78]. The concentration of suspended sediment varies directly with the rate of stream flow (turbulence) and inversely with the size of particle.

Sediment deposition marks the end of the erosion process. Eventually the transport forces begin to diminish and when the resistive forces dominate, the soil particles come to rest. Deposition is a highly selective process with the heavy, coarser materials settling out first, followed by the lighter materials further downstream. The problem arises in that the site for deposit of the erosion debris is often inconvenient as mentioned earlier.

Soil Productivity - a Renewable Resource

Because the erosion processes just described reduce the productivity of the soil it might be useful to consider the productive constituents of the soil as a composite resource which is renewable. Specifically, this composite resource consists of the soil structure, its organic content, the amounts of plant nutrients available in the soil, its moisture profile, the soil pH, and the population of soil organisms both those beneficial to plant growth and those detrimental. These soil constituents enhance agricultural productivity by providing a suitable seedbed for germination, supplying the water and nutrients necessary for plant growth, and providing a suitable soil structure to support the development of a root system. In general, productivity is enhanced because these soil constituents provide an ecosystem which is supportive of agricultural crop growth.

This composite resource, soil, can be viewed as a renewable or flow resource with the future rate of flow affected by man's use and subject to a critical zone [25, p. 39]. The critical zone refers to a range of diminished rates of flow of the resource as a consequence of human action. Once the rate of flow falls below the critical zone, reversal of the decrease in flow is not economically feasible.

The productivity of the soil is characterized as a flow resource because different units of the resource are available for use at different points over time. This flow of different soil units over time does not refer to the availability of different acreage from year to year. Rather, the ecosystem comprising a given acreage is different from year to year; that is, the moisture supply, nutrient content, amount of organic matter, soil structure, populations of organisms and chemical composition of the soil are different each year. In this sense, then, the productivity of the soil is a flow resource just as solar radiation and a babbling brook are flow resources.

While the rate of flow this year, the suitability of the soil ecosystem for crop production, does not diminish the rate of flow next year, man's use of the resource this year can adversely affect the rate of flow next year.[1] In other words, the present suitability of a given acreage for crop production does not diminish the future potential of that acreage. Both now and in the future there is a flow of productivity available for exploitation. Man's present use of the resource in exploiting its productivity, however, may diminish the future flow, the future productivity of the soil.

The productivity of the soil is renewable in that certain constituents removed or destroyed in the course of crop production can be

[1]An important distinction is drawn between the rate of flow of the resource and man's rate of use of the resource. There is a certain new quantity of the flow resource which becomes available each period. Man's rate of resource use is not necessarily the same as the rate of resource flow but man's rate of use, as with hunting a biologic species, or man's manner of use may reduce the future flow of the resource.

replenished. The soil's fertility can be restored by the same natural processes which formed the soil in the first place or by man through the application of fertilizers. Thus, the future flow of productivity can be augmented. However, the future flow of soil productivity is subject to a critical zone. If the soil is exploited in a manner which reduces its productivity below a critical level it may become impossible to restore the flow of productivity. In this sense the soil resource is exhaustible. If the soil is continually exploited without regard for erosion control, the critical zone for soil use might be crossed. Once deep gullies have formed or most of the topsoil has been removed by erosion, the decline in productivity might be irreversible [25, p. 39].

To avoid the economic exhaustion of the soil for agricultural use, present use for crop production must be accompanied by effective erosion control measures. There is evidence that such concerns have not always been acted upon in the past. In 1935 it was estimated, based on soil surveys and erosion surveys, ". . . that erosion had already ruined approximately 100 million acres for practical cultivation" [73, p. 150]. Technologies are available for controlling soil loss and preserving soil productivity. The available soil conservation practices should be employed if the critical zone for irreversible soil degradation is to be avoided.

Management Practices for Erosion Control

To introduce the discussion of erosion control methods, recall that soil erosion by water is a physical process of detachment and transport which requires the energy of water as it impacts on the soil surface as rainfall and as it flows over the soil surface as runoff. The control of soil erosion requires the dissipation of the erosive energy of moving water. The emphasis will be on measures to control sheet and rill erosion. The omission of specific practices for controlling gully erosion does not imply that gully erosion is an insignificant source of sediment. It has been shown, however, that the best way to control gully erosion is to control runoff and sheet-rill erosion above the gully head or potential gully channel [52].

An obvious target for erosion control measures is the source of runoff and erosion, rainfall. If rainfall occurred more frequently and with less intensity and duration, runoff and soil erosion would be reduced. The state of the art does not presently allow significant alteration in rainfall patterns, however, so attention must be focused on two other approaches. First, minimize runoff by maintaining high water intake rates for the soil and by increasing the ponding of water in small depressions on the soil surface. Second, absorb or reduce the energy of falling and flowing water. In keeping with these general approaches, practices for erosion control are designed to accomplish one or more of the following: (1) dissipate raindrop energy, (2) reduce the volume of runoff, and (3) reduce the velocity of runoff.

The first management practice considered involves the selection of crops and crop rotations. The crop grown on the land contributes to erosion control by providing a vegetative canopy over the soil surface which absorbs raindrop impact. Water falling to the ground from the intercepting plant possesses a small fraction of the energy which the original raindrops would have imparted to the soil surface if they had struck the ground directly. Also, the stalks of the vegetation serve to reduce runoff velocity by obstructing the flow of surface water. Of lesser importance but still significant, the roots help bind soil particles together increasing their resistance to detachment by the erosive forces of water. The different types of crop cover are rated in Table 2.1 in terms of their ability to reduce soil loss compared to fallow land.

Table 2.1. Effect of vegetative cover on erosion [11, p. 246]

Type of Cover	Soil-Loss Ratio (%)
Fallow	100.0
Row crop	40.0
Small grain	10.0
Meadow	.6

By rotating protective crops such as oats or hay with row crops, soil losses can be reduced. The cropping and management factor in the universal soil loss equation, which is discussed in Chapter V, reflects the reduction in soil loss associated with a particular crop rotation.

Another method for controlling soil loss centers on the management of the crop residue from the preceding year. If the residue is plowed under as in conventional moldboard plowing, the roots and stalks beneath the surface will still serve to hold the soil somewhat but there is no surface protection. As an alternative to clean plowing, a tillage system such as chisel plowing, strip-till planting, or slot planting can be used which leaves all or part of the previous crop residue on the surface. Chisel plowing employs a subsurface sweep which loosens the top 6 inches or so of soil without turning the soil over. Some of the residue is incorporated but 50% or more remains on the surface. Strip-till planting, hereafter referred to as till planting, uses an 8- or 10-inch surface sweep which removes residue and a 2- or 3-inch layer of topsoil directly over the row. The seed is planted behind the sweep in the same operation. Depending on the row width, between 66% and 80% of the surface is covered with crop residue. Slot planting employs a fluted coulter to open a narrow slot in the untilled soil for planting the seed. With this method, 100% of the residue is left on the surface. Slot planting results in poor seed bed conditions so that stands and yields suffer somewhat.[1] The presence of the surface residue serves to absorb raindrop impact and obstructs the runoff water reducing the flow velocity. In these two ways a surface mulch tends to reduce soil loss on agricultural land.

The choice of tillage method can also be used to control erosion both through its implications for crop residue as discussed in the preceding

[1] Donald Erbach, Associate Professor of Agricultural Engineering at Iowa State University. Private communication, April 4, 1977.

paragraph and through its effect on the infiltration rate of water depending on the physical condition of the soil surface after tillage. Conventional moldboard plowing leaves no residue but does produce a very rough, cloddy soil surface. As a result, water infiltrates well and the rough surface is conducive to ponding which holds runoff. The soil clods provide a poor seedbed, however, requiring disking and harrowing after plowing. These secondary tillage operations, while essential for adequate seedbed preparation, reduce ponding and contribute to surface sealing. The result is that, with conventional tillage, primary and secondary, runoff and soil losses are high.

There are two variations on conventional moldboard plowing; one is tillage in the spring and the other is fall tillage following the harvest. Compared to spring plowing, fall tillage saves time during the busy spring planting period, results in higher yields[1] and incurs lower tillage costs because smaller equipment can be used. Fall plowing results in greater soil losses, however, because the soil lies fallow over the winter without the protection of crop residue. Chisel plowing results in a smoother surface than moldboard plowing so there is less ponding but the presence of the residue results in less soil loss overall. Till-planting, because of the presence of the surface mulch, provides soil conditions conducive to water intake as does slot-planting.

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[1]With fall plowing the soil has time to "mellow" before planting. The winter rains on fall-plowed ground, along with the freezing and thawing of the ground over the winter tend to break down soil clods providing a better conditioned seed bed. With finer soil particles there is better seed-soil contact and better germination. The end result is better stands and higher yields.

The latter three tillage systems can all be classified under the rubric of minimum tillage. The minimum tillage system selected for use in the model was till planting since this system allows the maximum residue cover consistent with good crop stands and results in acceptable levels of soil loss.[1] The other tillage methods included for analysis in the model are conventional tillage with fall-plow and with spring-plow.

In addition to crop management and tillage system, there are two conservation practices which can be employed to reduce soil loss on slopes, contouring and terracing. Performing tillage operations and planting along the contour on slopes reduces soil loss by detaining runoff and increasing the infiltration of water into the soil. The remaining runoff has less detachment and transport capability because the flow velocity has been reduced. Contouring is most effective on slopes between 3% and 7% [11, p. 58]. On steeper slopes, runoff from intense rains may overtop rows at which time contouring loses its effectiveness for controlling soil loss.

Terraces consist of a ridge and a channel laid in pairs across the slope to impede the downhill flow of runoff. In effect, terraces divide long slopes into a series of shorter slopes. Thus, the velocity of runoff flow between terrace ridges is reduced because the slope length is shortened. Where soils are permeable as in the Nishnabotna River Basin, the terrace channels serve to pond the water until it can infiltrate the soil. In the process, most of the soil that was eroded from the terrace

[1]Soil loss of 5 tons per acre or less.

interval is deposited in the channel. In this manner, most eroded soil is trapped in the field and never enters surface water supplies.

Reasons for lack of adoption

With average soil loss for the nation around 12 tons per acre per year while the tolerable level for soil loss set by the Soil Conservation Service is from 1 ton to 5 tons per acre depending on soil type, why aren't erosion control techniques applied more widely? A study at Iowa State University examined this question as it applied to farmers in Western Iowa [42]. Several reasons were found for the farmers' reluctance or inability to invest in more soil erosion control: (1) high per unit output cost related to small farm size, (2) uncertainty of payoff period due to renter tenure status, (3) lack of profitability of erosion control from a short run private perpsective, (4) low farm income levels, and (5) lack of information about erosion control benefits.

This study examines policies directed at the third reason, the profitability or unprofitability of erosion control from the standpoint of the individual farmer. The amount of concern expressed within state and federal government agencies for greater erosion and sedimentation control indicates a gap between the private profitability of erosion control and the profitability as viewed from the public perspective. The reason for the gap is the existence of externalities associated with the dual problems of soil erosion and sedimentation. The depletion of productivity occasioned by soil loss could be described as involving a temporal externality. The short planning horizon of the farmer does not fully consider the cost imposed on future generations by the depleted productivity of the soil which may result from his efforts to maximize short-run profits. A longer time horizon would recognize the long-run profitability of soil conservation to maintain productivity into the future.

The other problem occasioned by soil loss, sediment pollution, can be regarded as involving a spatial externality. The damage caused by sedimentation usually occurs offsite from the source of pollution. The farm operator who generates the sediment pollution does not bear the full cost of removing the sediment from reservoirs or channels downstream or purifying the turbid water for use by downstream municipalities. Because of both externalities a greater degree of soil loss will be generated by private operators than is desirable from a social perspective.

Remedial policy options

Complete elimination of soil loss and the related externalities is not possible [78, p. 61] nor is it desirable from the standpoint of Pareto optimality. As Buchanan and Stubblebine explain [23], the Pareto optimal resolution of an externality requires that the externality generating activity be reduced to the level where the marginal benefit is just equal to the marginal cost of curtailing the externality. Based on the premise that it is socially desirable to reduce soil loss below existing levels, various policies are simulated with that objective in mind. No attempt is made to assess the socially desirable level of soil loss. The 5-ton limit set by the Soil Conservation Service for Marshall soil is accepted as one possible goal although intermediate levels of soil loss are also considered. The distributional aspects of the policies are not evaluated because the model employs a typical farm concept based on average farm characteristics in the river basin. Such a model is not able to deal with the distribution of policy impacts about the mean.

The remedial policies which are evaluated with the model can be classified into three groups:

(1) Bans and regulations -- make illegal certain activities which are sources of offsite pollution damage, prohibit certain activities which are unprofitable in the long run from a social viewpoint because those activities deplete the productivity of the soil,

(2) Soil loss tax - an attempt to internalize the offsite damage from soil erosion, and

(3) Subsidies for conservation practices - make soil-conserving farm practices more profitable from the private viewpoint.

CHAPTER III. ANALYTICAL APPROACH

Policy Simulation

The anlytical approach of this study is an application of computer simulation for the evaluation of selected resource and environmental policy options. Computer simulation is a technique which allows the social scientist to bring his problem area into the laboratory where experimentation can be conducted under controlled conditions. A mathematical model, representative of the topic under investigation is constructed for computer solution. Each solution is a simulation of an outcome in that segment of the real world represented by the model. Exogenous variables that affect the problem are controlled in the laboratory by specifying their values as parameters for the model. The independent variables being studied can then be assigned different values and the computer solution of the mathematical relationships in the model constitutes a simulation of the impact of these causitive factors on the subject of interest.

In this study, the model represents agricultural production in the Nishnabotna River Basin, a Southwestern Iowa sub-basin with a drainage area of 2,800 square miles within the Missouri River drainage system. The exogenous variables which are controlled as parameters in the model are crop prices, input costs, the productivity of agricultural inputs, weather conditions, soil variables, and topographical features. The independent variables under investigation are alternative environmental policies and the subject of interest is the effect of these policies on the dependent variables, soil loss, sedimentation, net farm income, crop production and the farmer's choice of technology and land use.

Study Area

The study area for this analysis, the Nishnabotna River Basin illustrated in Figure 3.1, contains 1.8 million acres from parts of twelve counties in Southwest Iowa. The predominant soil type in the basin is Marshall silty clay loam [51, p. 73]. The soils in the Marshall series are dark colored silty soils with moderate permeability and are well-drained. The formation of these soils is from a loessial origin and the native vegetation was prairie. The topography of the area is hilly with the typical slope gradient between 2% and 14%. The soils are rated as well-suited to moderately suited for row crops in the Iowa-Soils-2 survey but are subject to erosion [100]. About 95% of the study area lies within the Marshall Soil Association area as shown in Figure 3.1. The simplifying assumption was made, therefore, that all the soil in the basin is Marshall soil.

Most of the acreage in the basin is devoted to agriculture as indicated by Table 3.1. Only the tillable land and permanent pasture, a total of 1.6 million acres were included in the land base for the model. The remaining land, slightly less than 200,000 acres, was not engaged in agricultural production and, therefore, would not be subject to the policies designed to control soil loss from agricultural lands. Tillable land encompasses cropland, that is land planted in crops, hayland, and

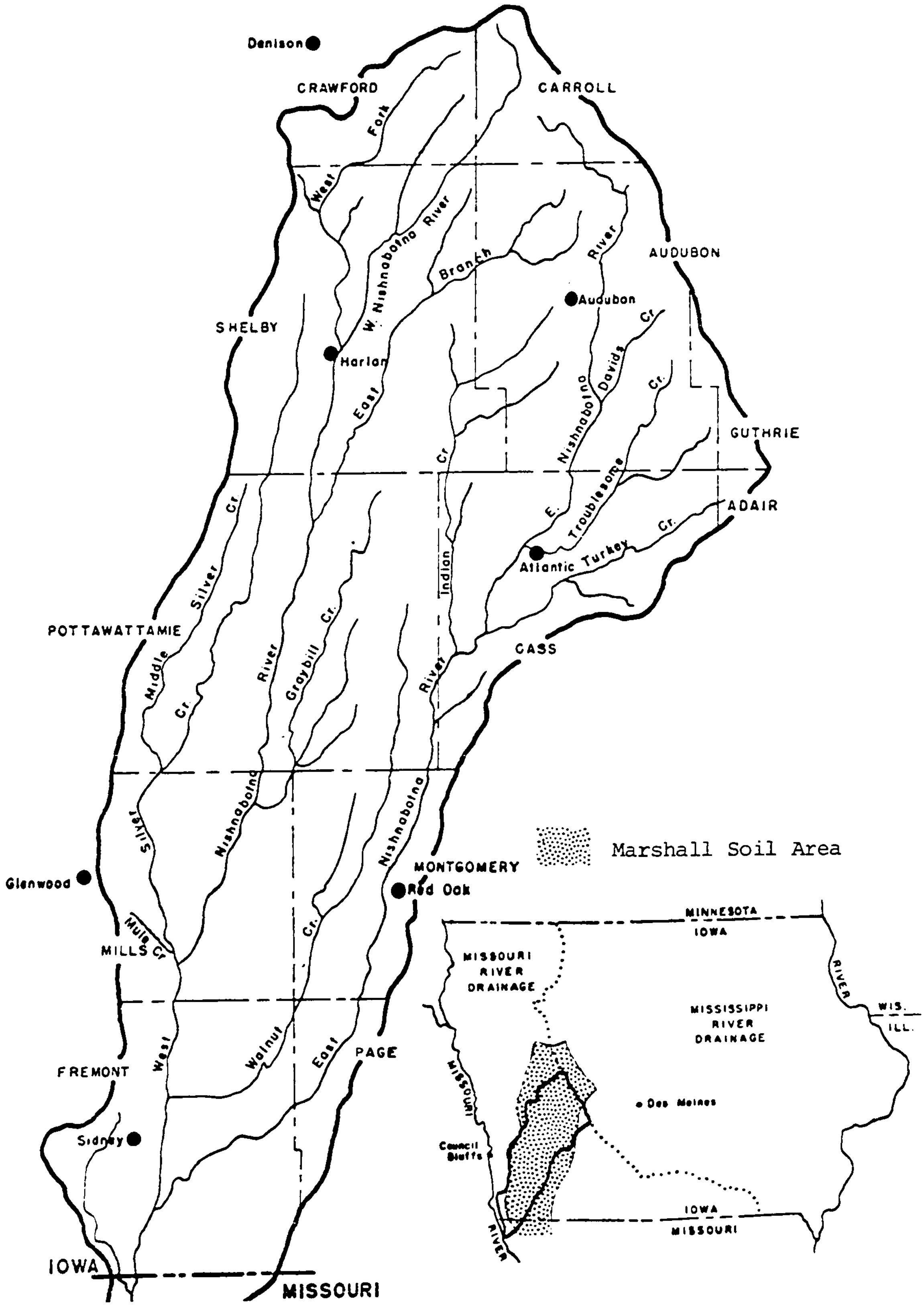

Figure 3.1. The Nishnabotna River Basin

Table 3.1. Land base in Nishnabotna River Basin[a]

Total tillable land	1,470,646		
Permanent pasture	179,060		
		1,649,706	Subtotal
Other land[b]	99,934		
		1,749,640	Total land inventoried in CNI
Urban	61,490		
Water	5,879		
		1,817,000	Grand total for River Basin

[a]Sources used in developing this table: USDA computer tape derived from 1967 CNI for Iowa; Land Use Table, Final from Southern Iowa River Basin Study, table dated January 4, 1977; 1975 Potential Cropland Study by USDA-SCS mimeo. July 1976 [99].

[b]Other land includes farmsteads, orchards, vineyards, bush fruit, forestland, unproductive miscellaneous land (e.g. mine tailings, sink holes and unclassified soils). Excludes urban, federal noncropland, and water area which were not inventoried in the CNI.

rotation pastureland. Permanent pasture refers to land that is not rotated with crops. The distinction between hayland and pastureland is that the pasture is grazed whereas the forage from the hayland is cut and utilized off the site of growth. The most important distinction, though, is between tillable land and permanent pasture. Tillable land, while all of it may not have been committed to crops in the survey year, e.g., hayland and rotational pasture, is nonetheless arable land which could be planted in crops. Permanent pasture on the other hand has limitations that render it unsuitable for crop production.[1] The tillable land and pasture land in the resource base for the model is classified into land classes according to the slope of the land (Table B. 10).

The principal crops grown in the region are the row crops, corn and soybeans. In 1975, the most recent year for which statistics are available [48], 727 thousand acres were planted in corn and 364 thousand acres were planted in soybeans. Along with corn and soybeans, oats are also grown as a cash crop but secondarily oats are often planted as a nurse-crop in establishing meadows of alfalfa and other hay varieties. All together, 89 thousand acres of oats were planted in 1975. Hay of all types including alfalfa and clover-timothy was produced on 107 thousand acres. Other crops, of lesser importance in the river basin, are grain sorghum, 4 thousand acres, and wheat, 10 thousand acres. As a producing area, the Nishnabotna River Basin with 5% of Iowa's land area, produced 4% of the corn, 5% of the soybeans, 4.8% of the oats and 4.4% of the hay grown in Iowa in 1975 [48].

The Marshall soils in the river basin, while suited for crop production are also highly erosive, particularly on the steeper slopes which are a common feature of the area's topography. That erosion

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[1]The SCS usage of the term permanent pasture is based on actual land use and, therefore, would include arable land that has traditionally been committed to pasture [103, p. 82]. The use of the term here is more restrictive and refers to land which cannot be tilled for crops without making improvements such as installing drain tile, removing rocks, or building an access road, etc.

presents a serious hazard for agriculture in the Nishnabotna and other river basins in the Missouri River Drainage Area has been mentioned often by agricultural economists. Davis made the following observation in a recent article appearing in the Journal of Soil and Water Conservation [27]. "The hilly loess soils along the Missouri and Mississippi Rivers are among the more erosive in America." The erosion problem in the region is exacerbated when intensive rotations of row crops like corn and soybeans are pursued by area farmers. Studies conducted under the supervision of John F. Timmons [18, 42] have documented average soil losses in the neighborhood of 17 to 20 tons per acre. On some lands in the area, losses of 60 tons per acre have been recorded. Because erosion rates from agricultural activities in the area are above the national average of 12 tons per acre, the Nishnabotna River Basin is an interesting laboratory for the analysis of erosion control policies.

Linear Programming

Policy analysis in the river basin was conducted with a linear programming model. Linear programming is an optimization technique which selects from among a set of feasible plans that plan which maximizes or minimizes a linear objective function which is defined over all feasible plans [85]. The set of feasible plans contains all those plans that satisfy a system of linear restrictions. The restrictions are usually expressed in the form of linear inequalities.

There are three features that are characteristic of all problems which are amenable to solution by linear programming. The problem must involve a quantifiable objective which can be achieved or enhanced by pursuing a plan of action composed of, and selected from, a variety of activities. The choice of activities, however, is constrained by resource limitations or other restrictions.

In this application, linear programming was employed to maximize net farm income from producing and selling certain crops grown according to specified rotations. The maximization procedure was subject to constraints on the amount of land from each land class that was available for production in the river basin. In addition, various other constraints were imposed to simulate the alternative environmental policies to be analyzed.

<u>Linear programming assumptions</u>

While linear programming enjoys wide applicability to a variety of problems, there are restrictive assumptions which must be met for the application to be valid. These assumptions are briefly discussed in the context of the present application.

1. Linearity: The objective function in the problem and all constraints on the set of feasible solutions must be linear in the activities defined for the problem. The linearity requirement is met by the objective function in this model since net farm income is expressed as a linear function of the crop production activities and the crop selling activities. The problem of diminishing marginal returns which would destroy linearity by giving rise to increasing costs is avoided by using fixed input proportions for each production activity. The fixed

proportions are based on an "optimal" input mix, i.e., an optimal equipment set, fertilizer application, etc. A larger output of a particular crop rotation could be obtained at constant cost by applying another complement of the optimal input mix. The constraints also comply, as they are expressed as a system of linear inequalities and equalities.

2. Additivity: The total amount of a resource used in several production activities must be equal to the sum of the amounts of the resource used in each of the production activities. This requirement is satisfied by the limited land resources available since the commitment of 5 acres from a particular land class to each of 3 crop activities results in the use of 15 acres in total.

3. Divisibility: Inputs and outputs are considered to be continuous, that is, capable of being divided into infinitesimally small units. By this assumption, the optimal solution could result in a fraction of an acre contributing to the production of a fraction of a bushel. In terms of reporting the results of the solution, the quantity of inputs and outputs would be rounded off to the appropriate number of significant digits. This assumption of divisibility conflicts in reality with the notion of adding a fixed complement of inputs to produce a constant increment in output which was employed to insure linearity in the objective function. This conflict can be theoretically resolved by making the assumption that the complement of inputs can be increased in fixed proportions by any scale desired, including a fractional scale, and that constant returns to scale will apply throughout. In reality, of

course, it is impossible to apply 1/640 of the optimal equipment set to 1/2 acre of land, but this assumption allows the model to achieve an optimal solution for production in the river basin. This solution then could be interpreted to the nearest integral input complement which would be associated with a 320 acre farm. Increments of 320 acres from a land base of 1.6 million acres is a fair approximation to continuity.

4. Finiteness: For solution of a linear programming problem the number of activities in the model must be finite and the constraints placed on the set of feasible solutions must be finite in number. The present model complies in that there are 115 activities[1] and 33 constraints.

5. Risk-free expectations: This assumption requires that crop prices, input prices, the production function and the outcome of the weather on yields are all known with certainty. In truth, there is a great deal of risk in agricultural production. Therefore, average values are used for these stochastic variables. But even with a normally distributed variable, the variance is required along with the mean to fully describe the distribution. The farmer will react differently to two activities with identical means if the variance of one is twice the other. Even with simple, normally distributed variables the incorporation of risk in the model would dictate a quadratic programming approach with the maximization of expected utility from net revenue as a possible choice for the objective function. The data requirements for this more complicated model are a quantum leap away from the data required for an LP model. The mean, variance and covariance of stochastic variables must

[1]Includes 109 crop production activities, 4 selling activities, a tax activity and a subsidy activity.

be known and farmer utility functions must be estimated. In light of these extreme data requirements, the use of the simpler, though less realistic, linear programming framework under the assumption of risk-free expectations offers a workable compromise.

Formulation of the model

A mathematical formulation of the linear programming model can be presented in general form as follows:

Maximize:

$$R = c_1x_1 + c_2x_2 + \ldots + c_nx_n + p_1q_1 + \ldots + p_sq_s \tag{3.1}$$

subject to:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \quad . \quad . \quad . \quad + a_{1n}x_n &\leq b_1 \\ &\vdots \\ a_{m1}x_1 + a_{m2}x_2 + \quad . \quad . \quad . \quad + a_{mn}x_n &\leq b_m \end{aligned} \tag{3.2}$$

$$\begin{aligned} a_{m+1,1}x_1 + a_{m+1,2}x_2 + \ldots + a_{m+1,n}x_n - 1q_1 &= 0 \\ &\vdots \\ a_{m+s,1}x_1 + a_{m+s,2}x_2 + \ldots + a_{m+s,n}x_n - 1q_s &= 0 \end{aligned} \tag{3.3}$$

and:

$$\begin{aligned} x_i &\geq 0 \text{ for } i = 1,\ldots n \\ q_i &\geq 0 \text{ for } i = 1,\ldots s \end{aligned} \tag{3.4}$$

The objective function (3.1) is an expression for net farm income where x_j is the level of the j-th crop activity or rotation. For example, the unit level of activity C-C-S involves three acres of crops in sequence; two acres in corn and one acre in soybeans. The term $c_j < 0$ represents the total production cost of the j-th crop activity and all such terms are negative valued because costs detract from net revenue. The symbol q_i denotes the selling activity for the i-th crop with p_i, its price.

The land resource constraints on the model are represented by the m inequalities (3.2) where a_{kj}, the technical coefficient of the j-th crop activity for the k-th land resource, shows the amount of land class k required per unit of crop rotation j. A six-year crop rotation would require six acres for one unit of the rotation each year. The amount of land of class k available for production is indicated by b_k.

The s equality constraints (3.3) are the crop transfer rows in the model where a_{rj}, the output coefficient, denotes the amount of the r-th crop produced by crop activity j. Each transfer row requires that the amount of the crop sold must equal the total of the crop produced in all activities.

The final n+s inequalities (3.4) involving the terms x and q are the nonnegativity constraints which state that the model is not allowed to produce or sell negative amounts of output in any activity. During the policy simulations two additional activities were introduced to the model to represent a tax policy and a subsidy policy. Two more constraint rows were added to tie in the level of the tax activity to the level of soil loss and to equate the level of the subsidy activity to the acreage committed to the subsidized practice.

Policy Simulations

The above paragraphs outline the linear programming model which was used to simulate the effects of the alternative environmental and resource policies. All together, twelve policy simulation runs were made with the model. Taking into account three price scenarios and the various tax and subsidy levels considered, 138 individual solutions were obtained for analysis. The simulation runs are outlined below:

1. Base run
2. Ban on fall moldboard plowing
3. Ban against straight row cultivation on slopes
4. Ban on fall-plow and straight-row cultivation
5. Soil loss limit of 5 tons per acre
6. Soil loss tax
7. Soil loss tax with a ban on fall-plow
8. Subsidy for contouring
9. Subsidy for minimum tillage
10. Subsidy for contouring with a ban on fall-plow
11. Subsidy for minimum tillage with a ban on fall-plow
12. Combined subsidy on minimum tillage and contouring

Price Scenarios

To increase the generality of the simulation results and thereby widen the applicability of the conclusions derived from those results, three alternative price scenarios were represented in the model. These scenarios are the low price-relative, the normal price-relative and the high price-relative.[1] The price relatives were developed using the ten years from 1966 to 1975 as a calibration period. This period is of interest because it spans an interval of sharp price changes in agriculture. Since 1973, crop prices have been stimulated by increased demand for exports. The year 1973 also marks the escalation in energy prices partly due to OPEC actions.

The high price-relative reflects the relative price situation in the year when the ratio of crop prices to input prices was at its highest for the ten-year period. The normal price-relative depicts the average ratio of crop prices to input prices over the calibration period. Finally, the low price-relative indicates the lowest relative price ratio during the ten years.

To ascertain the value of the price-relative for each scenario, a ratio was formed between the appropriate values of the crop price index and the input price index. The index for agricultural input prices and the index for crop prices in Iowa are shown in Table 3.2. The highest price-relative was 249/166 = 1.5 in 1974 and the lowest price-relative was 94/104 = .90 in 1969. The average price-relative for the ten-year period was 1.11.[2]

[1] The term price-relative is used to refer to the ratio of crop price level to input price level.

[2] Parenthetically, an average value greater than unity means that in the base year, crop prices were low relative to input prices when compared to the period as a whole.

Table 3.2. Price indices - 1967 base year

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Inputs[a]	100	100	100	104	109	113	121	146	166	182
Crops[b]	108	100	92	94	101	109	110	195	249	222

[a]The input price index is for the U.S. as a whole not just Iowa as an Iowa index could not be found. Source: [95].

[b]Source: [48].

In forming the high price-relative scenario, actual costs and prices from 1974 were used. Since relative changes in net farm income are more meaningful for comparative purposes than absolute changes, the normal price-relative and low price-relative scenarios were formed by adjusting crop prices while holding input prices invariant. The adjustments made in crop prices to construct the normal price-relative scenario and the low price-relative scenario were derived from the two series of price indices over the ten-year period. To generate the normal price-relative scenario, 1974 crop prices were multiplied by the factor .74 so that the ratio of crop price index to input price index would equal 1.11.[1] The low price-relative scenario was constructed by multiplying 1974 crop prices by the factor .60 so that the ratio of price indices would

[1]
$$\frac{\text{Crop price index 1974}}{\text{Input price index 1974}}\ x = 1.11$$

$$(1.5)x = 1.11$$

$$x = .74.$$

equal .90.[1]

The high price-relative scenario could be construed as depicting the relative prices which would prevail if the recent high levels of export demand for U.S. agricultural commodities continues into the future. The normal price-relative would be typical of relative prices if supply and demand return to historical trends. Finally, the low price-relative would typify the relative price ratio in the less likely event that agriculture would suffer a decline compared to other sectors of the economy.

---

[1] $$\frac{\text{Crop price index 1974}}{\text{Input price index 1974}}\, x = .90$$

$$(1.5)\,x = .90$$

$$x = .60.$$

CHAPTER IV. ECONOMIC DATA SET FOR THE NISHNABOTNA RIVER BASIN

The previous chapter described the linear programming model that was used for policy analysis in this study. In this chapter the development of the economic data series required for application of the model is discussed. Chapter V documents the development of the physical data set. The data requirements for the model were extensive, necessitating the development of a set of crop activities or crop rotations, detailed cost data for each crop activity, crop yields, soil loss coefficients for each crop activity, sediment delivery ratios, suspended sediment coefficients showing the contribution of each activity to the stream sediment load, and a land data base for the river basin. The material in this chapter and the next would be of most interest to the researcher planning to employ the methodology used in this study. The casual reader may want to omit these two chapters.

Activities

An important part of the data series is the set of crop activities since it is from these activities that the crop production plan is selected with the objective of maximizing net farm income. For realistic results the activities must be representative of agricultural production in the area. Foresight must also be applied in including activities which, although not predominant in the present, might be selected by farmers under incentives of the various environmental policies to be evaluated.

All together 109 crop activities were allowed in the model. These are presented in Table 4.1. The activities were developed from three basic crop rotations; corn-corn-soybeans (C-C-S), corn-soybeans-corn-oats-meadow-meadow (C-S-C-O-M-M) and corn-oats-meadow-meadow-meadow-meadow (C-O-M-M-M-M) plus nonrotational hay and permanent pasture.[1] The C-C-S rotation was included because corn and soybeans are the principal crops in the basin and two years of corn followed by one year of soybeans is a common rotation in those crops. The rotation C-S-C-O-M-M was allowed because of the significant production of hay in the region along with the nursecrop oats. This rotation also affords a degree of erosion protection from the meadow sod, while still allowing intensive row cropping in corn and soybeans during half of the rotation. The third crop rotation, C-O-M-M-M-M, plus hay and permanent pasture, would offer soil conserving options for land use under strict conservation policies.

These crop rotations and hay production were defined for use on six land classes, class A1 and A through E. No cropping activities were allowed on classes F anc G because of the steep slope and severe erosion hazard. Only permanent pasture was allowed on these two steepest land classes as well as on other lands where permanent pasture was indicated, land classes AP, BP, CP, DP, and EP.[2] There were three tillage operations avail-

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[1]The distinction between hay and pasture is based on two points. Hay is cut and baled whereas pasture is grazed for forage. Secondly, hayland is periodically tilled in the course of meadow maintenance while pastureland is not normally tilled.

[2]For an explanation of the other lands designated for permanent pasture see pages 28 and 96.

Table 4.1. Crop activities in linear programming model[a]

Land class[b]	C_1	C2	C3	CC1	CC2	CC3	CT1	CT2	CT3	S1	S2	S3	SC1	SC2
A_1	X_1	X_2	X_3							X_4	X_5	X_6		
A	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}				X_{16}	X_{17}	X_{18}	X_{19}	X_{20}
B	X_{27}	X_{28}	X_{29}	X_{30}	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	X_{36}	X_{37}	X_{38}	X_{39}	X_{40}
C	X_{50}	X_{51}	X_{52}				X_{53}	X_{54}	X_{55}	X_{56}	X_{57}	X_{58}		
D	X_{69}	X_{70}	X_{71}				X_{72}	X_{73}	X_{74}	X_{75}	X_{76}	X_{77}		
E	X_{86}	X_{87}	X_{88}				X_{89}	X_{90}	X_{91}	X_{92}	X_{93}	X_{94}		
F														
G														
AP														
BP														
CP														
DP														
EP														

[a]Crop activity names are explained in Figure 4.1.

[b]See Table B.10 for description of land classes.

SC3	ST1	ST2	ST3	M1	M2	MC1	MC2	MT1	MT2	H	PP
				X_7	X_8					X_9	
X_{21}				X_{22}	X_{23}	X_{24}	X_{25}			X_{26}	
X_{41}	X_{42}	X_{43}	X_{44}	X_{45}	X_{46}	X_{47}	X_{48}			X_{49}	
	X_{59}	X_{60}	X_{61}	X_{62}	X_{63}	X_{64}	X_{65}	X_{66}	X_{67}	X_{68}	
	X_{78}	X_{79}	X_{80}	X_{81}	X_{82}			X_{83}	X_{84}	X_{85}	
	X_{95}	X_{96}	X_{97}	X_{98}	X_{99}			X_{100}	X_{101}	X_{102}	
											X_{103}
											X_{104}
											X_{105}
											X_{106}
											X_{107}
											X_{108}
											X_{109}

·able for the rotations. Conventional tillage (contil) with fall plowing is the predominant tillage practice currently employed in the river basin. Conventional tillage with spring plowing is the more traditional tillage method but is not as popular due to the short planting period and lower yields. Spring plowing does provide greater protection from erosion, however. Third, till planting, a form of minimum tillage (mintil) performed in the spring achieves the greatest degree of erosion control between the three methods, but, based on field research, it too was assigned lower yields in the model. There were three options allowed in the set of crop activities with respect to conservation practices; no conservation treatment or straight row cultivation with no attempt to follow field contours, contour planting, and terrace construction.

The terraces planned for the model were designed with steep grassed backslopes and no tile outlets. The permeability of the soil is adequate on most slopes to make tile outlets unnecessary. In actuality, very few terrace systems in the river basin have been built with tile outlets.[1] Grassed waterways could be provided where necessary to remove excess water from the terrace channel. The field layouts were planned with parallel terrace ridges to eliminate point rows and facilitate farming operations. Terrace construction was allowed on land classes C, D, and E in conjunction with minimum tillage. Terraces were also allowed on B land if conventional tillage was planned.

Contour planting with conventional tillage is effective on A and B

[1]Lewis Grissom, District Conservationist in Mills County, private communication, April 13, 1977.

slopes and, therefore, was allowed on these lands in the model. On C land, slopes between 5% and 9%, contouring with contil is effective only on slope lengths up to 200 feet [111, p. 37]. Since only 5,400 acres out of the 194,400 acres of C land in the river basin had a slope length of 200 feet or less, contouring with conventional tillage was not allowed on C land. With minimum tillage, contouring could be effectively employed on these slopes and was, therefore, allowed in the activity set with mintil on land class C as well as on A and B.

A final activity option open to the model was to leave some land fallow. In all simulation runs the program was free to choose fallow for all or part of any land class. During the policy simulations, however, this option was taken only rarely. A system is provided in Figure 4.1 for naming each of the crop activities. This legend will be useful for identifying the crop activities listed in the results tables in Appendix C.

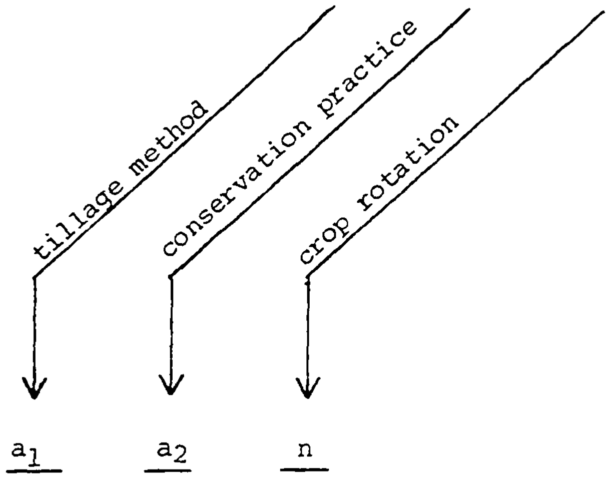
Typical Farm Size

The basis for much of the cost data depends on the selection of a typical farm size. The farm size would affect, of course, the optimal equipment set for each of the tillage methods. The equipment set, in turn, would influence the equipment ownership costs, repair costs, labor costs, and fuel costs. The determination of the typical farm size for the model was based on the actual distribution of farm size in Southwest Iowa. According to the "1975 Farm Business Summary for Southwest Iowa" [50], the average farm size in the region containing the Nishnabotna River Basin was 322 acres. On this basis, a size of 320 acres was adopted for the typical farm in the model.

Example: Corn-corn-soybeans (rotation 1) in conventional tillage with contouring

Symbol: C C 1

$\underline{a_1}$ $\underline{a_2}$ $\underline{n}$



$\underline{a_1\text{: tillage}}$	C = conventional tillage fall plow
	S = conventional tillage spring plow
	M = minimum tillage
$\underline{a_2\text{: practice}}$	C = contour
	T = terrace
	Omitted = no treatment (straight-row)
<u>n: rotation</u>	1 = Corn-corn-soybeans
	2 = Corn-soybeans-corn-oats-meadow-meadow
	3 = Corn-oats-meadow-meadow-meadow-meadow

<u>note</u>: H by itself denotes meadow (hay)
PP indicates permanent pasture

Figure 4.1. Crop activity legend

Ownership Costs

With the size of the typical farm operation established, it was possible to begin developing the production costs for each of the activities in the model. An important component of production costs is associated with the farm equipment. In terms of cost per unit of output, machinery ranks second only to land. The first step in developing these costs is the selection of an efficient equipment set which will depend on the crops to be cultivated, the acreage to be farmed, tillage system, number of field days available during critical crop stages like planting and harvesting, and the topography of the land. The machinery in the equipment set must be suited to the tillage and crop system at hand. The implements must be matched so that they are mutually compatible with each other. Finally, the capacity of the machinery must be sufficient to accomplish planting and harvesting activities in a timely manner. If crops are put in late because of undersized equipment, the resulting yield penalty can make sizeable inroads into net farm income. The equipment sets designated for each rotation in the model are listed in Tables A.1.a through A.1.e.[1]

For purposes of discussion, equipment costs can be classified into two categories: ownership costs, often referred to as fixed costs and operating costs, which are a part of variable costs. Ownership costs include depreciation plus interest on the equipment or capital recovery,

[1]Considerable technical assistance in developing the equipment sets was provided by Donald Erbach and David Williams, faculty members in the Agricultural Engineering Department at Iowa State University.

insurance, taxes, and housing cost for the equipment. Operating costs encompass equipment repairs, fuel, oil, and operator labor costs.

Depreciation

Depreciation plus interest expense is the allocation of first cost minus salvage value on an annual basis over the life of the equipment. This annual equivalent payment which provides for replacement and return on equipment was calculated using the following formula:

$$D = B(a/p)_n^r - V(a/f)_n^r \quad [84, p. 94] \qquad (4.1)$$

where:

D = depreciation plus interest or annual equivalent of first cost less salvage,

B = initial list price of equipment,

V = salvage value after n years,

r = minimum attractive rate of return,[1]

$(a/p)_n^r = \dfrac{r(1+r)^n}{(1+r)^n-1}$, a capital recovery factor, and

$(a/f)_n^r = \dfrac{r}{(1+r)^n-1}$, a sinking fund factor.

The useful life of the equipment over which depreciation was calculated was assumed to be ten years. Some items of equipment will typically provide service over a longer life. Nonetheless, the above assumption implies that the equipment is replaced after ten years of service and any

[1]The interest rate charged for farm equipment loans by banks was used as a proxy. The bank rate was regarded as an effective annual rate of interest.

remaining serviceable life would be reflected in a higher salvage, or trade-in, value.

The fraction of original value remaining after ten years will vary between the different types of equipment. To calculate the appropriate salvage value as a fraction of original cost for each piece of equipment, four remaining value equations found in the Agricultural Engineers Yearbook [4] were used. Farm implements are classified into four groups according to their rate of depreciation. The four remaining value equations are listed in Table A.2 where the remaining value after 10 years, expressed as a fraction of initial cost was calculated for each implement group. To find the salvage value for each piece of machinery in an equipment set, the s-factor for the appropriate group would be multiplied times the initial list price of the implement.

The estimates of salvage value were used to calculate the annual equivalent of depreciation plus interest. The computational formula for this calculation was derived from Equation 4.1.

$$D = B(a/p)_n^r - sB(a/f)_n^r$$

$$D = B[(a/p)_n^r - s(a/f)_n^r] \tag{4.2}$$

The depreciation factor, the term in brackets in Equation 4.2, for each implement group appears in Table 4.2. Each factor is an annual rate to be multiplied by the initial cost of the equipment in finding the levelized annual equivalent of depreciation plus interest.

Table 4.2. Ownership cost factors for equipment

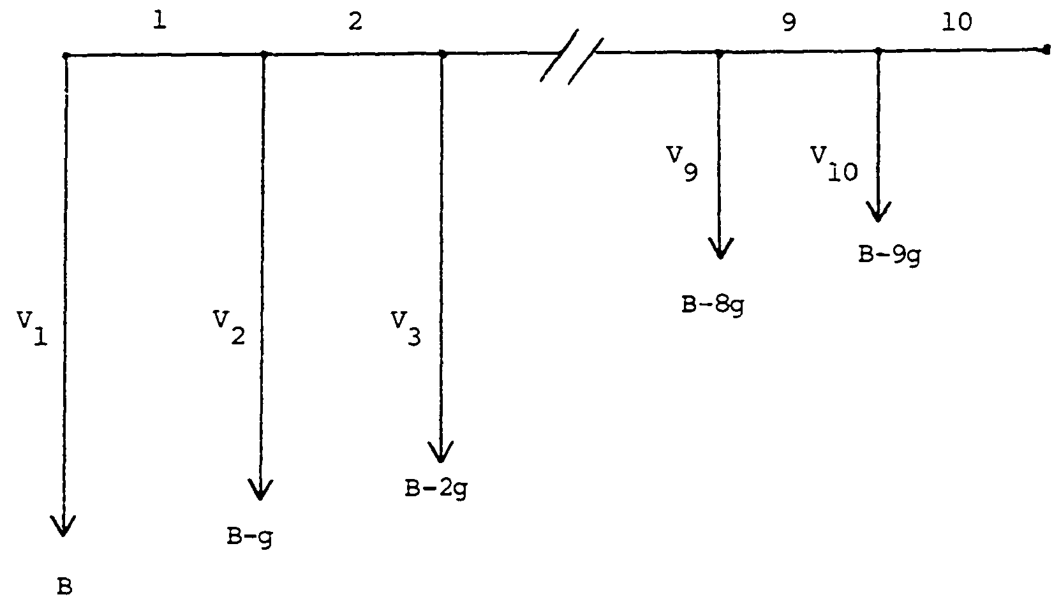
	Group 1[a]	Group 2	Group 3	Group 4
Depreciation plus interest	.14338	.14417	.14496	.13640
Insurance	.00377	.00375	.00372	.00399
Taxes	.02201	.02190	.02179	.02303
Housing	.01	.01	.01	.01
FIXED COST FACTOR	.17916	.17982	.18047	.17342

[a]Equipment in each implement group is described in Table A.2.

Insurance

The calculation of the annual charge for insurance as well as the charge for taxes on equipment can be explained in terms of the following algorithm. First, the costs of insurance and taxes could be estimated for each of the ten years of equipment ownership based on the remaining value of the equipment each year. Then the series of annual costs could be converted to future value terms for insurance and tax charges at the end of ten years. Finally, the two future values could be multiplied by a sinking fund factor to obtain the levelized annual equivalent charges for insurance and for taxes. While this method has heuristic appeal, during the actual computation a short cut was used. The current charges were expressed in terms of a gradient series which was converted directly into a levelized annual equivalent charge [84, p. 71].

Based on this method, the computation of the annual equivalent insurance charge is illustrated first. The annual insurance premium is determined by the insured value of the equipment which was taken to be the value remaining at the beginning of the year. Payment of the insurance premium was assumed to be due at the beginning of the year. With straight line depreciation, the remaining value of the equipment at the beginning of each year can be expressed as a decreasing gradient series as illustrated in Figure 4.2.



V_1 = insured value on which premium due the first year is based

V_i = $B-(i-1)g$, insured value on which premium due the i-th year is based

$g = \frac{B-V}{10}$ annual depreciation

Figure 4.2. Beginning-of-year gradient series to represent remaining value of equipment for calculating insurance premium

Since all other costs are calculated following the end-of-year convention, it is desirable to convert this beginning of year series to the equivalent end-of-year series. The conversion was accomplished by multiplying each term in the series by (l+r) and then delaying each term until the end of the period. The sum (l+r)B occurring at the end of the period is equivalent to the amount B occurring at the beginning of the period. The converted series appears in Figure 4.3.

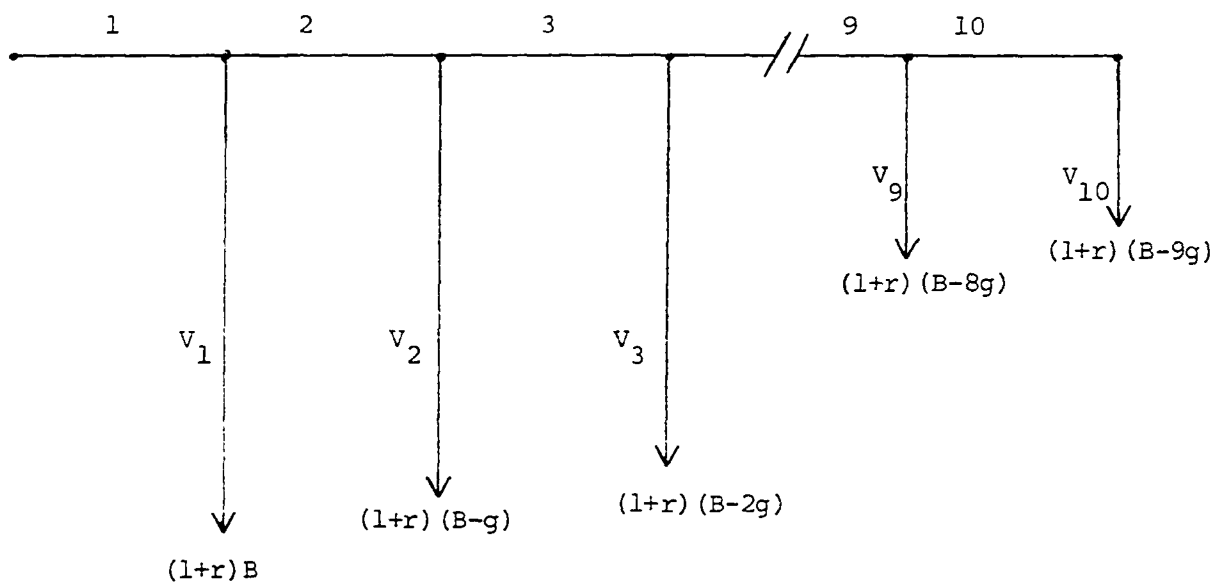


Figure 4.3. End-of-year gradient series to represent remaining value of equipment for calculating insurance premium

Following Smith [84, p. 71], the annualized end-of-year equivalent of the decreasing gradient series for insured value can be represented by

$$a_1 = B' - g'(a/g)_n^r \tag{4.3}$$

where:

a_1 = annualized end-of-year equivalent of the insured value of equipment,

$B' = (1+r)B$,

$g' = (1+r)g$,

B = initial list price,

g = annual straight line depreciation charge,

$(a/g)_n^r = \frac{1}{r} - \frac{n}{(1+r)^n - 1}$ annual equivalent of a \$1 gradient series,

r = 9%, and

n = 10.

Substituting for B' and g' in Equation 4.3 and factoring (1+r):

$$a_1 = (1+r)[B-g(a/g)_n^r]. \tag{4.4}$$

The annual premium for insurance coverage is commonly \$5 per \$1,000 of insured value. The annual equivalent charge for insurance can, therefore, be written

$$I = .005\ a_1. \tag{4.5}$$

Substituting for a_1 from Equation 4.4,

$$I = .005(1+r)\,[B-g(a/g)^{r}_{n}]. \qquad (4.6)$$

Substituting for g in Equation 4.6

$$I = .005(1+r)\,[B - \frac{B-sB}{n}(a/g)^{r}_{n}],$$

where sB = V and s indicates the fraction of initial list price which remains as salvage value.

$$I = B(.005)(1+r)\,[1 - \frac{(1-s)}{n}\,(a/g)^{r}_{n}] \qquad (4.7)$$

The factor to the right of B in Equation 4.7 is the annual end-of-year equivalent insurance charge factor and appears in Table 4.2 for each implement group.

Taxes

The annual equivalent charge for property taxes was similarly figured on the remaining value of the equipment. It was assumed that equipment value is assessed as of the beginning of the year but the tax is due at the end of the year. Figure 4.4 illustrates the assessed value on which the tax is based, appearing in an end-of-year series at the time each annual tax payment is due. The annualized equivalent of the decreasing gradient series above can be represented by

$$a_2 = B-g(a/g)^{r}_{n} \qquad (4.8)$$

where a_2 = annualized end-of-year equivalent of the assessed value of equipment.

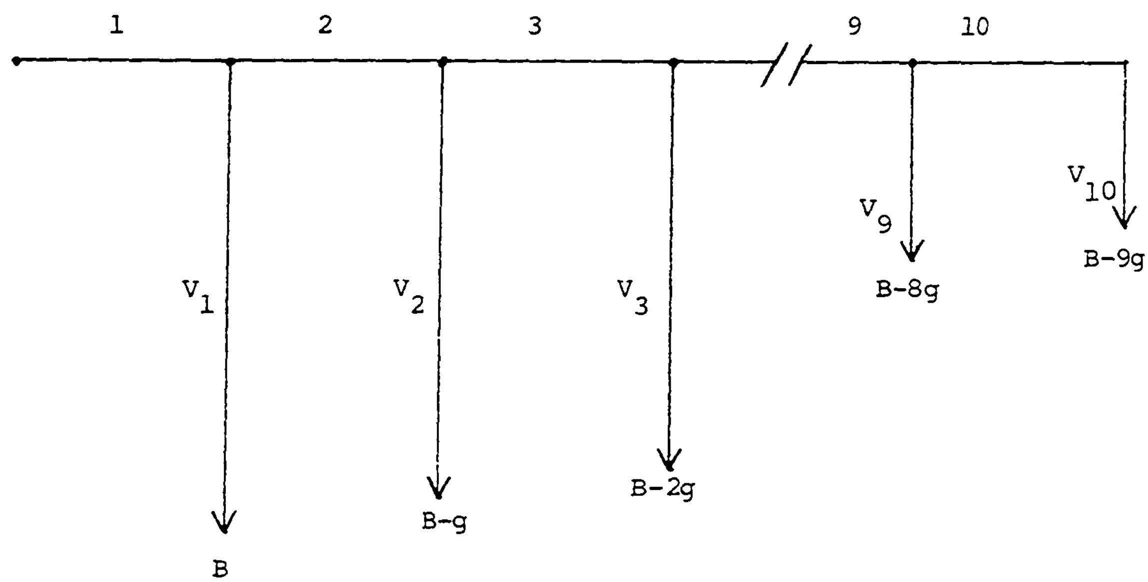


Figure 4.4. End-of-year gradient series to represent assessed value of equipment for tax purposes

The average mill levy for the property tax in the twelve counties comprising the river basin is 76.19 mills per $1 assessed value. Assessed value is 27% of fair market value. Since a mill is 1/1000 of a dollar, the property tax amounts to $.07619 per dollar of assessed value and $.02057[1] per dollar of market value of equipment.

The annual equivalent property tax can be expressed

$$T'' = .02057a_2 \qquad (4.9)$$

or, making the same substitutions used in deriving Equation 4.7,

$$T'' = B(.02057)[1 - \frac{1-s}{n}(a/g)^r_n] \qquad (4.10)$$

[1] ($.07619)(.27) = $.02057.

A sales tax must be paid on the equipment at the time of purchase. The sales tax rate in Iowa is 3%. The annual end-of-period equivalent of this one-time charge for the sales tax is

$$T' = .03B(a/p)^{r}_{n}. \tag{4.11}$$

The combined annual equivalent charge for both the sales tax and property tax is

$$T = B\{.03(a/p)^{r}_{n} + .02507[1 - \frac{1-s}{n}(a/g)^{r}_{n}]\}. \tag{4.12}$$

The tax charge factor to the right of B in Equation 4.12 appears in Table 4.2.

A charge for housing the equipment was included since, even if housing is not provided, the farmer will bear a cost in the form of higher maintenance and/or reduced salvage value on the equipment. The annual housing charge is estimated as 1% of the initial list price of the equipment [19, p. 6].

The sum of the cost factors for depreciation plus interest, insurance, taxes, and housing, yields the fixed cost factor for equipment ownership. The ownership cost factors from Table 4.2 were multiplied times the initial list price to calculate the annual ownership cost for each implement which appears in Tables A.1a through A.1e.

Operating Costs

In developing the operating costs for each rotation, reference was made to the sequence of field operations for each tillage system under each rotation. These field operations which are listed on the left-hand side of Tables A.3a through A.3i will be the same whether performed on flatland or on slopes. The costs associated with performing each operation, of course, will vary with the slope of the land necessitating an operating cost figure for each rotation which is specific to the tillage system and the land slope class. To begin constructing this extensive data set, the operating costs were first calculated for level land and then adjusted for application to sloped land taking into account any conservation practice employed.

Labor

The field time required for each operation performed on level land was obtained from an ISU Cooperative Extension Service publication [49]. This field time estimate served as the basis for deriving equipment usage rates for calculating equipment repair costs, about which more will be said later, and also for figuring operator labor costs. The labor costs could not be calculated directly from the field times because adjustments had to be made for the additional time which the operator would spend preparing the equipment for use and adjusting and servicing the equipment during field operations. Most machinery requires field adjustment; seed hoppers on planters require frequent filling, and the tanks on herbicide and fertilizer applicators need to be replenished periodically. This labor time, which normally amounts to an additional 10% to 25% of the field time [20], is accounted for in a labor efficiency factor for each operation [34, pp. 230-232]. This number between 1.10 and 1.25, depending on the field operation, is multiplied by the field time to obtain the total labor time required for operating, adjusting, and field servicing the machinery for each field operation. These total labor requirements are reported in Tables A.3a through A.3i. A wage rate of $2.50 per hour[1] was applied to obtain the labor costs which appear in Table A.4.

Equipment repair cost

Earlier studies of this nature [51, 81] based repair figures on per acre repair cost estimates obtained from a study plot. However, these per acre annual repair costs are valid only when applied to equipment with annual use rates comparable to the use rates in the study from which the estimates were obtained. The estimates will not be valid when applied to acreage where the equipment size or equipment operations differ from the study plot. Furthermore, the per acre repair costs cannot be used to estimate annual repair costs for similar equipment on larger or smaller acreages than the study plot by merely extrapolating on the basis of the per acre cost figure. While the annual use of equipment may be linearly related to the size of the farm operation, annual repair costs are not linearly related to annual equipment use rates. As annual equipment usage increases, annual repair costs rise by a power function

[1]Source: [47, p. 90].

of the annual use rate.

Since this study includes minimum tillage and conventional tillage activities, equipment size and annual use rates will differ markedly between activities. Therefore, repair costs would vary significantly between different activities conducted on farms of the same acreage. With fewer operations involved in minimum tillage activities, equipment usage is reduced and so are repair costs. To more accurately reflect repair costs, an approach was adopted which bases repair cost estimates on the estimated usage of a particular size of equipment in each activity.

The heart of the usage-based method is a set of eleven total accumulated repair cost equations (TAR equations) which apply to the various types of equipment [20]. These equations and the implements to which each applies are listed in Tables A.5 and A.6. The TAR equations, which were derived from surveys of farm equipment repair costs by agricultural engineers are of the form

$$TAR = (a \times b \times L^{d})ILP,$$

where:

L = accumulated equipment use as a percent of the wear-out life of the equipment,

ILP = initial list price of equipment,

TAR = total accumulated repair cost,

a = constant which expresses the ratio of TAR to ILP when L = 100%,

and

b and d = constants which relate to the behavior of accumulated repair costs over the life of a specific piece of equipment. (Note: $b \times L^{d} = 1$ when L = 100%).

Annual repair costs can be estimated by finding the difference between the TAR estimates for two years in succession:

$$RC_n = TAR_n - TAR_{n-1}.$$

Even with the same rate of use each year, annual repair costs will rise over time due to accumulated usage and aging of the equipment. A levelized annual equivalent of this increasing series of repair costs was used as the annual estimate of repair costs in the model. The estimate was calculated by discounting the current cost of repairs in each year and summing to obtain the present value of repairs over the ten-year ownership period.

$$PV = \sum_{i=1}^{10} \frac{RC_i}{(1+r)^i}$$

where:

RC_i = repair cost in year i measured in current dollars,

r = effective rate of interest or discount, and

PV = present value of repair costs over ten-year life.

A capital recovery factor was applied to the present value of repairs to obtain the annual equivalent repair cost.

$$AER = \left[\sum_{i=1}^{10} \frac{RC_i}{(i+r)^i} \right] \frac{r(1+r)^{10}}{(1+r)^{10}-1} = \sum_{i=1}^{10} \frac{RC_i r(1+r)^{10-i}}{(1+r)^{10}-1}$$

where AER = annual equivalent repair cost. The annual equivalent repair cost estimates calculated by this method are listed for each piece of equipment in Tables A.1a through A.1e.

Fuel

Fuel costs were calculated on a per acre basis using the fuel requirements published by the ISU Cooperative Extension Service [5]. These fuel consumption rates, for field operations on level land, were adjusted to the 38-inch row spacing which applied in all rotations. Per acre fuel consumption for each operation is listed in Tables A.3a through A.3i. The fuel costs per acre, calculated using unit prices of 34.8¢ a gallon for diesel and 34.9¢ a gallon for gasoline[1] are reported in Table A.4. Lubrication costs, including oil and filters were estimated at 15% of fuel costs [6, p. 8].

Seed and Chemical Costs

Besides the operating costs associated with machinery, there were other variable costs related to seed and chemical inputs. Fertilizer costs were based on application rates recommended by Lloyd C. Dumenil, Associate Professor of Agronomy at Iowa State University. The fertilizer recommendations, included along with fertilizer costs in Tables A.7 and A.8, took into account average soil test values for Marshall soil and also incorporated special nutrient needs of each crop according to its position in the crop rotation. Rotations including legumes were credited with nitrogen (N) and the N fertilizer requirements were reduced

[1]Source: [47]. The 4¢ federal excise tax and 7¢ state motor fuel tax were subtracted from the reported price for gasoline since farm use of gasoline is exempt from these taxes.

accordingly.

The seed costs for corn were computed according to a desired stand of 21,000 plants per acre, the recommended population for Southwest Iowa [17, p. 5]. With 10% mortality, the desired seeding rate was .274 bushels per acre. A higher seed mortality for minimum tillage was not assumed because the till-plant system provides a suitable seed bed. The seeding rates and costs for the other crops were derived from the Midwest Farm Planning Manual [53] and are listed in Table 4.3.

Table 4.3. Seed cost per acre

	Seed per acre	Seed cost[a]	Cost per acre
Corn	.274 bu	$25.00 per bu	$6.85
Soybeans	1.0 bu[b]	$9.90 per bu	$9.90
Oats	2.5 bu[b]	$3.35 per bu	$8.38
Alfalfa and Brome	9 lbs & 7 lbs[b]	$.82/lb	$20.50

[a]Source [95].

[b]Source [53].

Insecticide costs were calculated from application rates recommended in "Summary of Insecticide Uses in Iowa for 1976 Crop Production" [87]. The most current literature was used in planning insect control to take into account recent bans on previously popular insecticides like aldrin. No insecticide was required for corn following soybeans. The basis for herbicide costs were the application rates suggested in "Weed Control Guide for 1977" [54] and "Chemical Crop Protection Guide" [24]. For soybeans and corn following meadow, Parquat was used for burndown of existing vegetation prior to planting. This burndown of weeds was not required for corn following soybeans since, with the early planting of corn, the sweep on the till-planter was sufficient to clear the seedbed of any weeds that might have already emerged. Insecticide and herbicide applications and costs are summarized in Table A.9.

Hauling, Drying and Storage Costs

The costs enumerated above account for the crop through harvest. There are three additional costs which are relevant following the harvest, costs for hauling, drying, and storage of the crop. The costs were computed on a per bushel basis from unit costs contained in an ISU Extension publication on crop production costs [88]. These costs were based on the following average yields: corn = 100 bushels per acre; soybeans = 35 bushels per acre; oats = 55 bushels per acre; and hay = 3.5 tons per acre. The following comments pertain to the calculation of the hauling, drying, and storage costs which are summarized in Table A.10. In estimating the hauling costs for all crops including hay, only the variable costs were computed at this point. The fixed costs associated with the wagons and tractors were already counted in the ownership costs for the equipment sets. Of the four crops, only corn required drying.

Each of the individual cost items described above were then tallied for each rotation to obtain the total cost for crop production on level land with spring plowing. A charge for the use of the land was not imputed and included in production costs. The cost of the land within the context of the model is regarded as a sunk cost. The linear programming problem is to allocate a fixed amount of agricultural land among alternative activities in order to maximize profit. The imputed charge for land is arbitrary and will not vary with the allocation of land across activities. Therefore, the land charge will not affect the programming solution and can be ignored. For the same reason no charge was made for property taxes on land. The production costs for flatland farming, land classes A and A1, are itemized in the first column of Tables A.11a through A.11g. To generate the other production costs in the tables associated with farm operations on sloped land and with different conservation practices, the following adjustments were made to the flatland cost factors.

Straight-Row Farming on Slopes

Consider first farm operations performed on sloped land without contouring. It has been estimated that labor time requirements would increase up to 10 percent over flatland farming times depending on the slope of the land.[1] The increase in flatland operating times for straight row farming on sloped land is due to reduced tractor speed and lost time on the uphill climb which is not fully offset on the downhill pass since the tractor governor holds the tractor speed in check. In line with the above estimates, it was assumed that the labor increments in the following table would be required for straight row farming operations on sloped land. By contrast, no increase in fuel

Table 4.4. Increased labor time for straight-row farming of sloped land over flatland times

Land class	B	C	D	E
Increment	+2%	+4%	+6%	+8%

consumption was calculated for farming operations straight up and down slopes over fuel consumption on level land. Compared with farming on level ground, there is more work involved during the uphill trip across the field but less work during the downhill pass. There are efficiency losses, of course, so that the increased fuel consumption traveling uphill is not completely offset by the reduced fuel consumption coming downhill, but the net increase in fuel consumption is very slight.

One way to quantify this slight difference in fuel consumption is

[1] George E. Ayres, agricultural engineer, Iowa State University Cooperative Extension Service. Private communication, February 22, 1977.

in terms of increased wheel slippage while climbing uphill. For example, on steep slopes wheel slippage might increase 33 percent from the 12 percent normal slippage on level ground to 16 percent slippage going uphill.[1] This increase in slippage of 4 percentage points translates directly into increased fuel consumption as more revolutions of the engine and tractor wheels are necessary in order to travel a given distance. To illustrate this increase, assume zero slippage initially. Suppose that, in this hypothetical base run, the tractor travels a given distance D and the fuel consumption is measured. The distance traveled could be expressed as:

$$D = x\pi d$$

where:

d = diameter of tire

x = number of revolutions by wheel

$\pi = 3.14$

With normal 12% slippage on level ground, the shorter distance traveled D' with the same amount of fuel is:

$$D' = .88\ x\pi d.$$

The distance remaining as a fraction of the distance already travelled can be written:

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[1] George E. Ayres, agricultural engineer, Iowa State University Cooperative Extension Service. Private communication, February 22, 1977.

$$R = \frac{D-D'}{D'} = \frac{.12\ x\pi d}{.88\ x\pi d}\ .$$

Let y = fuel consumed in each of the trials above. Thus, to travel the full distance D on level ground with 12 percent slippage, would require additional fuel equal to

$$\frac{.12\ x\pi d}{.88\ x\pi d}\, y.$$

Let total fuel required be

$$g = y(1 + \frac{.12\ x\pi d}{.88\ x\pi d}).$$

Now assume additional slippage of four percentage points as would occur traveling up a steep slope. With the original number of revolutions x and fuel consumption y, the distance traveled now equals only $.84\ x\pi d$. The distance remaining as a fraction of the distance traveled is expressed:

$$R' = \frac{.16\ x\pi d}{.84\ x\pi d}\ .$$

The additional fuel required is

$$\frac{.16\ x\pi d}{.84\ x\pi d}\, y.$$

Total fuel required is

$$g' = y(1 + \frac{.16\ x\pi d}{.84\ x\pi d}).$$

The increase in gas consumption with 16 percent slippage going uphill over 12 percent normal slippage on level ground can be expressed as a ratio:

$$\frac{g'}{g} = \frac{y(1 + \frac{.16\ x\pi d}{.84\ x\pi d})}{y(1 + \frac{.12\ x\pi d}{.88\ x\pi d})} = \frac{1.19048}{1.13636} = 1.0476$$

This ratio reveals that, in traveling up a steep slope, gas consumption would increase not quite 5 percent. Of course, traveling down the slope on the next pass through the field would not involve the increased slippage. Therefore, farming operations on a steep slope which increased slippage 33 percent on the uphill climb would increase fuel consumption at most just under 2.5 percent if slippage on the downhill pass were equal to the normal 12 percent slippage on level ground. In fact, slippage on the downhill trek would be less than 12 percent, resulting in a slight fuel saving. For purposes of illustration, suppose the downhill saving offsets one-half of the uphill increase. On balance, fuel consumption would increase a little less than 1.25 percent. With increased fuel consumption of such small magnitude, no adjustment in fuel consumption was made for farming up and down slopes since the variance in fuel consumption due to differing soil conditions would be expected to exceed 1.25 percent.

Contour Farming Costs on Slopes

In calculating labor costs for contour farming on slopes, the increased labor requirements in Table 4.4 do not apply. Contouring does require more labor time than flatland farming but not because of reduced tractor speeds going uphill. Operations on the contour involve mostly level passes through the field with the equivalent of only one trip up the slope in the course of contour field work. Upward adjustments in labor time and fuel requirements are necessary with contouring but for a different reason. Contouring on irregular grades results in the formation of short point rows where the grade of the slope changes. With point rows, equipment must be turned around more often. More turnarounds mean increased fuel consumption and increased operating time. Short point rows also imply slower average operating speed for the contoured field since farmers don't open the throttle all the way on a short row. A slower average operating speed, of course, will require more labor time to complete field operations.

A conservative estimate shows labor and fuel requirements increasing 5 to 7 percent on contoured slopes [73]. For contouring activities on slopes A, B and C in this study, labor times were increased 7 percent and fuel consumption was increased 5 percent over flatland values. Labor times were increased more than fuel consumption since the two factors associated with point rows would have a greater impact on labor requirements than on fuel requirements.

Farming Costs on Terraced Land

The costs of farming terraced land were derived in a straightforward manner from flatland farming costs. Two reports [40, 53] indicate that farming operations performed on terraced land entail roughly the same labor and fuel requirements as the identical operations performed on level land, provided the terraces are parallel and the terrace intervals are planned to accommodate the equipment size. Since the equipment is operated approximately on the contour there is no measurable increase in fuel or labor time because of the land slope. Furthermore, the parallel terraces eliminate point rows.

The grassed backslopes of the terraces, however, which take land out of cultivation, necessitate a proportionate reduction in all variable costs related to the acreage farmed. The land area lost to cultivation varies with the slope of the land and the required length of the backslope. This lost land area for terrace systems on different land slopes is expressed as a percent of total terraced land area in Table A.12. These percentages were used to make appropriate reductions in the variable costs on terraced lands in Tables A.11a through A.11g. Finally, the annualized equivalent cost for terrace construction and maintenance from Table A.12 were added to the farming costs to obtain the total cost of crop production on terraced land.

Fall-plow Costs

The preceding costs for conventional tillage crop activities were all predicated on spring plowing. Another tillage system employed by some farmers to avoid the rush of farming operations in the short spring planting period, is conventional tillage with plowing in the fall after the harvest. The major advantages with fall plowing are: (1) there is more time available for plowing in the fall than in the spring; (2) the danger of wet ground conditions in the spring delaying seedbed preparation and planting are reduced; (3) yields are higher due to better soil conditions for planting;[1] and (4) tillage costs are lower. Of concern to conservationists is the fact that fall plowing increases soil loss due to both wind and water erosion.

The fall-plow option was allowed for all three rotations in the model C-C-S, C-S-C-O-M-M, C-O-M-M-M-M. The cost of fall tillage differs from the cost of the spring-plow option primarily because the different timing of the farm operations allows the use of a different equipment set. With fall plowing, smaller equipment suffices because farming operations are spread out over a greater portion of the year and there is less soil preparation to be accomplished during the short and busy spring planting period. As a consequence, the equipment ownership costs associated with fall plowing are less than with spring plowing. Other costs associated with fall plowing are higher, however. Labor costs are a case in point since will fall plowing, labor is substituted for equipment. There is more calendar time for operations with fall plowing so equipment with smaller field capacity is used but this equipment requires more operating time and thus more labor time to cover the same acreage. In essence, the operation is less capital intensive since a smaller and less expensive equipment set is used but the smaller equipment set is used more intensively, that is, more hours are logged on the equipment each

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[1]As explained in Chapter II the soil has time to "mellow" following fall plowing through exposure to winter rain, and freeze-thaw cycles.

year. As a result, not only are operator labor costs increased but also repair costs are slightly higher. On balance, however, the saving in ownership costs dominates and the overall cost of the fall-plow system is less.

The cost adjustments made in deriving the fall plow costs were based on an Indiana farm study which compared the costs of spring and fall tillage systems [28]. Only tillage costs were compared since harvesting costs would be invariant between the systems. The results of the study revealed the following adjustments in costs when comparing fall-plow to spring-plow. These figures were used to adjust the tillage

Table 4.5. Fall-plow versus spring-plow costs

	Adjustment in per acre cost
Equipment ownership costs	-38%
Fuel and repairs	+9%
Labor	+11%

costs for the C-C-S rotation from the spring-plow to the fall-plow option.

Table 4.6. Adjust spring tillage costs per three acre rotation of C-C-S

	Spring Tillage Cost		Fall Tillage Cost
Equipment ownership costs	$78.84 x .62	=	$48.88
Fuel and repair costs	17.85 x 1.09	=	19.45
Labor costs	11.94 x 1.11	=	13.25

Adding these tillage costs for the fall-plow option to the harvesting costs results in the total expenditures for labor, repairs, fuel and equipment associated with growing and harvesting the crops in the rotation.

Table 4.7. Fall plow costs for C-C-S rotation (three acres)

	Labor	Fuel and Repairs	Equipment Ownership Costs
Tillage costs	$13.25	$19.45	$48.88
Harvest costs	4.76	6.56	46.79
	$18.01	$26.01	$95.67

Adding these costs to the expenditures for other inputs like seed, fertilizer, drying costs, etc., results in the total cost for the rotation listed in Table A.11f and used in the model.

The fall-plow costs for the C-S-C-O-M-M rotation were adjusted in a similar manner. The adjustments made in labor and fuel costs from the spring-plow option apply only to the tillage operations involved in the C-S-C part of the rotation. Adjustments were not made in the labor and fuel costs associated with O-M-M crops in the rotation because fall plowing would not affect them. Similarly, the adjustments in equipment ownership costs and repair costs were based only on equipment used in tillage operations for C-S-C. For equipment which is also used for O-M-M, only the pro-rata share of the equipment time for C-S-C was adjusted.

Table 4.8. Adjust spring tillage costs for C-S-C portion of C-S-C-O-M-M

	Rotation	
	Spring Tillage Costs	Fall Tillage Costs
Equipment ownership costs	\$71.78 x .62	\$44.50
Fuel and repair costs	15.42 x 1.09	16.81
Labor costs	12.56 x 1.11	13.94

Adding these tillage costs for the fall-plow option for C-S-C to the tillage costs for the O-M-M portion of the rotation results in the total tillage costs for the rotation with fall tillage.

Table 4.9. Fall-plow tillage costs for C-S-C-O-M-M rotation (six acres)

	Labor	Fuel and Repairs	Equipment Ownership Costs
C-S-C	\$13.94	\$16.81	\$44.50
O-M-M	16.85	17.46	84.34
	\$30.79	\$34.27	\$128.84

Adding these costs to the other expenditures like custom combine costs, drying costs, feed, and fertilizer, results in the total costs for the rotation listed in Table A.11g and used in the model.

The costs for the third rotation C-O-M-M-M-M when using the fall-plow option were not adjusted since the only crop effected in the rotation is corn and there would be no significant change in the equipment set when comparing fall-plow with spring-plow. Therefore, there would be no measurable change in costs between the two tillage systems. There would be a slight increase in soil loss and a slight increase in corn yield with the fall-plow option. Both of these changes have been incorporated in the model.

Hay Production Costs

The final cost series to be described is for hay as a crop. Hay cannot be profitably produced in a single year the way corn or soybeans can. It takes a year to establish a good alfalfa-brome hay meadow before cutting can begin. Usually in that first year oats are planted along with the hay as a nursecrop. The oats develop quickly, holding the soil and shielding the young hay until it can establish a meadow. Beginning in the second year as many as three cuttings of hay can be obtained annually. After five or six years of cutting, meadow renovation becomes necessary to control weeds. At that point the meadow is plowed and reseeded along with the nursecrop.

Given this pattern, the cost of hay production was calculated in two parts, meadow establishment cost, incurred during the first crop year, and the meadow maintenance and harvesting cost for hay, incurred during each of 5 crop years. The costs associated with a six acre hay production activity were obtained primarily from an ISU Cooperative Extension Service publication on crop production costs [88] and are detailed in Table A.13.

CHAPTER V. PHYSICAL DATA SET FOR THE NISHNABOTNA RIVER BASIN

Compared with the extensive cost data, the task of developing the physical data for the model was easier in one sense but more difficult in another. The task was easier in that the size of the physical data set is smaller than the economic data set. However, the task was complicated by the fact that the physical relationships associated with soil loss and transport, while extensively researched, are extremely complex and not as well-documented as the economic relationships in crop production. A major part of the physical data set was devoted to quantifying the most important dependent variable in the study, soil loss from agricultural lands due to water erosion.

Estimating Soil Loss with the Universal Soil Loss Equation

Soil loss due to erosion by water involves the detachment and transport of soil particles through the energy of moving water. The kinetic energy of water on land is related to the dropsize of rainfall and its intensity and to the velocity of runoff water which depends on slope gradient, the length of slope and the roughness of the soil surface.

The energy of surface runoff has both detachment and transport potential whereas the energy of rainfall is principally evidenced in the detachment of soil particles. Certain tillage and other crop management and conservation practices can be employed to reduce the amount of soil loss per acre by lessening the impact of raindrops on the soil surface, increasing the permeability of the soil surface to facilitate water infiltration and thereby reduce runoff, decreasing soil detachability, and decreasing the velocity of runoff.

The many factors which affect the rate of soil erosion by water are relfected in the universal soil loss equation which has been developed for use in predicting soil loss per acre. The equation which has been undergoing refinement and improvement for thirty years and is based on nearly 10,000 plot-years of data [116, p. 10] appears in the form [116]

$$A = RKLSPC$$

where:

A = average annual soil loss in tons per acre,

R = rainfall factor,

K = soil erodability factor,

L = slope length factor,

S = slope gradient factor,

P = conservation practice factor, and

C = cropping and management factor.

The equation predicts the average annual soil loss from sheet and rill erosion. The soil loss estimates for each crop activity in the model are listed in Table B.1. The term soil loss must be clarified for interpretation of the predictions based on the equation. Soil loss as predicted by the equation refers to the gross movement of soil off the slope segment under study. Thus soil loss must be distinguished from the sediment yield of a field. The latter concept refers to sum of soil losses from all slope segments which comprise the field minus the deposition of eroded soil at the end of slopes and in low spots in the field. Furthermore, erosion is not synonymous with soil loss. On a contoured and stripcropped slope much of the soil which erodes from the planted soil strips will be trapped by the interspersed sod strips. Soil loss from such a slope as predicted by the equation will be less than the total erosion of soil from between the sod strips.

One further clarification; the soil loss predicted by the equation is an estimate of the long run average annual soil loss that would occur with typical rainfall over a 22 year rainfall cycle [115, p. 6]. The soil loss in any particular year may deviate significantly from the predicted loss if the amount and intensity of rainfall during that year deviates from the 22 year average. The discussion which follows describes briefly the factors that comprise the universal soil loss equation and explains how the factor values were derived for the river basin in this study.

Rainfall factor - R

The rainfall factor is a measure of the erosiveness of the average annual pattern of rainfall in an area. This single rainstorm parameter is actually an interaction term which is equal to the value of the product of two rainstorm characteristics; the total kinetic energy of the storm and its maximum thirty minute intensity. Analysis of a large amount of data compiled at the Runoff and Soil Loss Data Center indicated that soil losses from agricultural land are directly proportional to the rainfall factor. This factor measures the interactive effect of raindrop impact and runoff turbulence in dislodging and transporting soil particles from the surface.

The R-factor for the Nishnabotna River basin equals 167 and was derived by calculating a weighted average of the rainfall factor in each county in the river basin. The rainfall factor for each county was weighted by the fraction of the total river basin area which is comprised by that county.

Soil-erodibility factor - K

Some soils erode more readily than others. The erodibility factor is a measure of the amount of erosion occurring on a standard plot of land from a standard intensity of rainfall. The standard plot is defined to be a one acre fallow field plowed in straight rows up and down the slope which has a gradient of 9% and a slope length of 72.6 feet. The selection of this standard plot by Wischmeier and Smith [116] was arbitrary but it was selected because it is representative of the conditions typically existing on the sample plots from which most of the measured soil loss data used in deriving the universal soil loss equation were obtained. With this standard as a reference point, the soil loss occurring under different conditions can be estimated easily. The standard intensity rainfall is defined to be one unit of the rainfall intensity index (R-factor).

The erodibility factor for different soils was established experimentally by measuring the amount of soil lost on a standard plot during a storm of known intensity (R value) and applying the formula:

$$K = \frac{A(\text{measured soil loss})}{R}$$

The K-factors for the different Iowa soils range from .17 to .49. The differing degrees of erodibility are due to differing physical characteristics of the soil such as soil texture, soil structure and stability of that structure, soil permeability to infiltration by water, soil depth, and soil content of organic matter.

The K-factor for Marshall Silt Loam, the predominant soil type in the river basin, is .32. In the Nishnabotna river basin where the R-factor is 167, an acre of Marshall soil on a 9% slope with slope length of 72.6 feet would lose .32 x 167 = 53.44 tons when fallow as a result of average rainfall during a year.

Slope factors - LS

Soil loss increases with slope steepness and length. Long, steep slopes result in less infiltration by rainfall so the volume of runoff from a given rain is greater. Moreover, the velocity of runoff from such slopes is faster. The combination of greater volume and velocity of runoff results in more soil-loss from a given rainstorm.

The LS-factor takes into account the interaction of the slope gradient effect and the length effect on soil losses from slopes which differ from the standard plot. The LS-factor for any slope can be calculated from the formula [116, p. 9]:

$$LS = \sqrt{L}\ (.0076 + .0053s + .00076s^2),$$

where

L = slope length in feet, and

S = slope gradient as a percent.

The LS-factor for each land class in the river basin was calculated from the above equation by substituting the average value of the slope gradient in that slope phase for S and substituting the weighted average of the slope lengths in that slope phase. In calculating the LS-factor for terraced land, the effective slope length was used. In effect, terracing divides an existing slope into several shorter slopes according to the spacing of the terraces. The effective slope length between two adjacent terraces is equal to the distance between the toe of the backslope on the upper terrace and the bottom of the channel on the front-slope of the lower terrace. The soil loss from a study plot of fallow land with a slope gradient and length different from the standard plot can be estimated by multiplying the soil loss from the standard plot by the LS-factor associated with the study plot.

Conservation practices factor - P

Two conservation practices were allowed in the model, contour planting and terracing. The practice of contouring reduces soil loss by impeding the flow of surface runoff. The reduced velocity of runoff is attended by a reduction in the detachment and transport of soil particles. Further, the prolonged detention of rainwater on the soil surface results in greater infiltration which reduces the volume of runoff. The reduction in volume and velocity of runoff from contouring can reduce soil loss by as much as one-half on slopes of 3% to 7% [11, p. 59]. The effectiveness of contouring decreases as the slope of the land increases with the P-factor approaching 1.0 on steep land where runoff breaks through contoured rows. Also the effectiveness on flatter land decreases with the P-factor approaching 1.0 as the land slope approaches zero. In the limit then, on extremely flat land or very steep land the soil loss with contoured rows would be 1.0 times the soil loss with straight rows and thus contouring has no effect. On intermediate slopes the effectiveness of contouring varies with the maximum effect occurring on 3% to 7% slopes where the P-factor equals .5.

Contouring can be effectively applied on slopes steeper than 7% as long as the length of the slope is appropriately short. Table 5.1 shows the upper limit on the slope length in each slope gradient for efficient soil-loss control through contouring with conventional tillage.

Table 5.1. Slope length limits for contouring [116, p. 37]

Slope (%)	Maximum Slope Length (feet)
2	400
4 to 6	300
8	200
10	100
12	80
14-24	60

In the study area, there are 194,400 acres of tillable slope C land which includes slopes of 8%. Only 5,400 acres of this land has a slope length of 200 feet or less. Since contouring with conventional tillage cannot be effectively applied on the bulk of slope C land or steeper land in the Nishnabotna River Basin contouring was an allowable activity within the model only on land classes A and B with conventional tillage.

With till-planting on the contour, runoff and soil loss are further reduced by the till-plant ridges and the strips of residue between the rows. Thus contouring with a till-plant system could be effectively applied on steeper land than contouring with conventional tillage. Accordingly, contouring was allowed in the model on slope C land as well as on A and B land when the till-plant system was used.

The interaction effect due to ridging and residue strips is not captured by either the C factor for till-planting or the P-factor for contouring. As suggested by Wischmeier [113] this interaction effect should be incorporated by adjusting the P factor. Quantitatively, this interaction effect was evaluated by Wischmeier on land with 10% slope as follows:

ridging factor	.8
residue strip factor	.8
	.64

The ridging and residue effect on land class C was taken to be the same as the observed value in Wischmeier's study, .64. On other slopes, it seems reasonable that the efficiency of ridging and residue for reducing soil loss would vary systematically with the land slope as does the efficiency of contouring alone with conventional tillage. The P-factors used in the model for contouring were based on Beasley's figures for conventional tillage [11, p. 59] and adjusted for ridging and residue strips in the case of till-planting. The P-factors for contouring with conventional tillage and the adjusted P-factors with minimum tillage are contained in Table 5.2.

Table 5.2. P-factor values for contouring in universal soil loss equation

Land Class	Contil	Mintil[a]
A	.60	.60 x .68 = .41
B	.50	.50 x .60 = .30
C	-	.55 x .64 = .35

[a]The ridging and residue factor with mintil for each land class was evaluated based on the following assumptions:

1. The ridging and residue factor has its minimum value on a 3% slope as does the P-factor for contouring with conventional tillage.
2. The ridging and residue factor achieves its maximum values of 1.0 at a zero slope and the same steep slope where the contil P-factor reaches its maximum value of 1.0.
3. At any intermediate slope, the ridging and residue factor will lie the same fraction of the interval between its minimum and maximum values as the P-factor for conventional tillage lies between its minimum and maximum values at that slope.

Parallel terraces reduce soil loss by effectively dividing long slopes into a series of shorter slopes. It is assumed for the terraces in the model, that the primary concern in the terrace layout is that the terraces be parallel for improved efficiency in machine operations. A major objection raised by farmers against conventional terraces which follow the contour is the increased field time required during farming operations due to the existence of point-rows between nonparallel terrace ridges. Parallel terraces eliminate these time consuming point-rows.

The spacing of terraces in the model takes into account the gradient of the land. The terrace interval was reduced on the steeper lands in accordance with the recommendations in the Soil Conservation Service Field Office Technical Guide [101]. For optimal machine efficiency during farming operations the recommended intervals between terraces were adjusted slightly to accommodate equipment set up for 38-inch rows.

The terraces in the model have steep grassed backslopes to minimize the land lost to cultivation as a result of terrace construction. The backslopes are maintained in sod to stabilize them. Thus, on a terraced field, all but the backslope can be cultivated. Table A.12 indicates the terrace interval, length of backslope, and adjustment for reduction in cropped area for terraces on each land class. Tile outlets for the terraces were not planned because of the relatively high permeability of Marshall soil. If needed on steeper slopes, grassed waterways could be built.

Terrace channels serve to hold runoff allowing the deposition of transported sediment in the channel. Terrace maintenance includes plowing the terrace channel so as to move the deposited sediment back upslope. Terracing is very effective in reducing soil loss by reducing the effective slope length and by allowing for the deposition of much of the transported soil particles from the field above the terrace channel. The P-factors for terracing are listed in Table 5.3.

Table 5.3. P-factor values for terracing in universal soil loss equation [11, p. 62]

Land class	P-factor
B	.10
C	.11
D	.13
E	.16

Cropping and management factor - C

The C-factor captures the combined effects of the many crop cover and management variables that affect soil loss. A partial listing of these interrelated variables includes the vegetative canopy provided by the crop itself, the management of crop residue, the effects of tillage on the texture of the seedbed surface, the crop rotation, and the tillage system used. These variables interact with the timing of highly erosive rains during the season so a C-factor for a particular cropping system must reflect the typical rain patterns in a specific region.

The C-factor is constructed to measure the ratio of soil loss from land cropped under specified management practices to the soil loss from the same site under a tilled but fallow condition. The soil loss that would occur from a particular field under a continuous fallow condition is indicated by the product RKLS from the soil loss equation. The cropping of the field and the associated management practices which are employed will result in less soil loss than from the fallow field. The C-factor adjusts the soil loss estimate to reflect the cropping and management practices.

The C-factors for most of the crop activities were obtained from a Soil Conservation Service publication [97]. A published factor was not available for the rotation C-S-C-O-M-M or the nonrotational hay activity. These factors were derived according to the U.S.D.A. Handbook [116] in Tables B.2 to B.5. The C-factors for the rotations used in the model appear in Table 5.4.

Stream Sediment Load

Rather than soil loss per se, what is more important to water quality is sediment yield. The sediment yield of a watershed measures the amount of sediment originating within the watershed boundaries that is transported by the stream leaving the watershed. The yield is expressed in tons per acre based on watershed area. The sediment yield in conjunction with the volume of stream flow determines the concentration of suspended sediment or stream sediment load. Contributing to sediment yield are sheet and rill erosion from the action of rainfall and runoff on agricultural land and gully and channel erosion from concentrated streams of runoff. Of course, not all of the sediment from sheet and rill erosion is transported to the mouth of the watershed. Some of this

Table 5.4. Cropping and management factor values for universal soil loss equation[a]

C-C-S[b]	
Fall-plow	.41
Spring-plow	.36
Mintill[c]	.20
C-S-C-O-M-M[d]	
Fall-plow	.18
Spring-plow	.16
Mintill[c]	.11
C-O-M-M-M-M[b]	
Fall-plow	.036
Spring-plow	.032
Nonrotational hay[e]	.01

[a]With conventional tillage the crop residue was assumed to be left on the surface after harvest.

[b]Source: [97].

[c]Assumed: 4000-6000 lb/ac of corn residue.
1500-2000 lb/ac of soybean residue.

[d]From Tables B.2 through B.4.

[e]From Table B.5.

sediment is deposited at the base of the slope from which it eroded, in grass waterways or in depressions in the field, etc. There is little deposition in graded channels and gullies because Marshall soil is a silty loam. Most of the eroded Marshall soil particles are in the silt-clay size range and are easily transported by runoff of minimum velocity [7], p. 850].

In determining the impact of suspended sediment on water quality, the soil loss from sheet and rill erosion estimated by the universal soil loss equation must be adjusted downward for deposition and upward for gully and channel erosion. Piest and Spomer found that in the Missouri Valley loessial region where the Nishnabotna River Basin lies, gully erosion averages 20% and sheet-rill erosion 80% of the sediment yield measured below the gully head [72, p. 853]. An add-on for gully erosion equal to 25% of the sheet-rill erosion estimated by the USL equation was made in working toward an estimate of sediment yield. This gully add-on was not made for terraced activities, permanent pasture activities or hay activities since gullying would be insignificant on land managed in these activities.

The adjustments in sediment load needed to account for deposition and channel scouring were handled by way of the delivery ratio. The delivery ratio reflects the efficiency of the transport system for carrying eroded soil particles. The delivery ratios used in this model were derived by Seay [81, p. 75] from the ratio of measured sediment yield to estimated sheet-rill and gully erosion. The value of the delivery ratio depends on many factors including the drainage area of the watershed, watershed shape, relief-length ratio of the watershed, channel gradient, straightness of the channel, and texture of the eroded material [76, p. 36]. Due to the complicity of factors involved, modeling of the delivery ratio was not attempted. Instead, the empirical estimates derived by Seay were used. His estimates for the Nishnabotna River Basin ranged from 20 to 29 percent, with the long time average (1940-1963) value being 26.7 percent. Because of the difficulty in deriving a single reliable estimate of the delivery ratio, three values were used in this model based on Seay's findings. The three alternative values used were .20, .25 and .30.

The final step in relating soil loss to stream sediment load is a conversion factor for translating sediment yield into milligrams per liter of suspended sediment in the stream. The needed conversion factor was derived from a relationship between soil loss per acre foot of runoff and suspended sediment expressed in milligrams per liter.

milligrams per liter x .00136 = tons per acre-foot of runoff [104, p. 191]

$$\text{milligrams per liter} = \frac{1}{.00136} \text{ tons per acre-foot of runoff.}$$

The long run average value for annual runoff in the Nishnabotna River Basin is 796,125 acre feet [81, p. 142]. The contribution of each crop activity to the stream sediment load can be estimated by the following equation:

$$\text{milligrams per liter} = \frac{\text{soil loss in tons}}{796{,}125 \text{ acre feet}} \times \frac{1}{.00136}$$

$$\text{milligrams per liter} = \text{soil loss in tons}$$

$$\times \frac{1}{(796{,}125)(.00136)} \text{ tons per acre foot.}$$

Since the contribution of a three or six acre crop rotation to stream sedimentation is slight, the scale was adjusted by a factor of one-thousand and expressed in thousandths of tons per acre-foot.

$$\text{milligrams per liter} = (\text{soil loss in tons})\left[\frac{1000}{(796{,}125)(.00136)}\right]$$

$$\times 10^{-3} \text{ tons per acre foot.}$$

Reducing this expression results in the following conversion factor which was multiplied by the soil loss from each activity to obtain the contribution to stream sediment load as presented in Tables B.6 through B.8:

$$\text{milligrams per liter} = (\text{soil loss in tons})(.9235912) \times 10^{-3}.$$

Crop Yield Data

The yields obtained from each crop activity comprise another important segment of the physical data set.

Various yield studies [1, 3, 28, 37, 75, 79, 82] were consulted which compare tillage methods in the corn belt states of Iowa, Illinois, Indiana and Minnesota, with the longest study spanning twelve years in Iowa. There are noticeable differences in corn yield between conventional tillage and till-planting within a single year reflecting the effect of particular weather conditions that year. Average yields over several years, however, reflect no major advantage of one method over the other for corn on all soil types.

On heavier soils in the cornbelt, however, conventional plowing for corn in the fall seems to have a slight edge over till-planting [28]. Till-planting however results in comparable and sometimes superior yields on lighter sandy soils [28]. Weather appears to be an important interacting variable for corn. Till-planting seems most likely to outyield conventional fall plowing on light soil in a dry year, however, the yield advantage disappears when there is adequate moisture in the soil [1].

Soybean yields with both conventional tillage and till-planting displayed less variance between years than corn in all studies, indicating that weather does not interact very much with tillage method in affecting soybean yields. Long term average yields for soybeans were nearly identical for both tillage systems [1, 3, 37, 75].

For purposes of this study soybean yields were set equal in the two tillage systems, but corn yields with till-planting were set 4% below yields with conventional fall plowing [28, p. 164]. In this manner, if till-planting should emerge from the model as the more profitable system it won't be because of overly optimistic yield estimates with the till-plant system. Oat and hay yields were set equal for both systems since these crops were drill-planted following disking without plowing under both conventional plow rotations and till-planted rotations in the model.

With respect to fall plowing versus spring plowing, no clear cut advantage emerged from the studies that would apply to all crops. Soybean yields were essentially identical under the two plowing options [79]. In the case of corn, several studies indicated a slight yield advantage for fall plowing [1, 37, 75] which has become the dominant practice in Iowa. Spring-plow corn yields expressed as a fraction of fall-plow yields ranged from 85.2% in the Illinois study by Griffith et al. [37] to 93.6% based on an as yet unpublished study by Donald Erbach in Iowa which was reported by Amemiya [1]. The disadvantage associated with spring plowing for corn observed in these studies could be due to occasional late planting when wet ground conditions delay spring plowing, to cooler soil temperatures at planting time following spring plowing and to soil clods in the seedbed following spring plowing. Even small clods prevent good seed-soil contact and adversely affect the germination of corn. With fall plowing, however, the freezing and thawing of the plowed ground during winter and late fall, and the early spring rains tend to "mellow" the soil and pulverize any clods. These factors are more important to the corn crop because of the earlier planting date. In western Iowa corn can be planted beginning in mid-April [91] while the best time to plant soybeans is mid-May [16]. By the time soybeans are planted there would be time for several rainfalls to have "mellowed" the spring-plowed soil and the soil would have warmed up sufficiently even with spring plowing. Therefore, spring plowing does not diminish soybean yields the way corn yields suffer. To be consistent with the above observations soybean yields in the model were set equal under spring and fall plowing but corn yields were penalized 7% under spring plowing [1].

In addition to the above yield differences between tillage systems, different yields were used on the various slope phases according to the Iowa Soils-2 Survey of the Marshall Soil Series [100]. The yield for the predominant erosion phase in each slope class in that survey was selected to represent the average attainable yield with high management under conventional tillage with fall plowing. Yields decreased with increasing slope due to the greater loss of topsoil and nutrients from erosion on the steeper slopes. Yields on contoured and terraced slopes were adjusted upward by as much as 12% based on findings in an Illinois study by Sauer and Case [80]. The favorable affect on yields from contouring and terracing is due to better infiltration of rainfall, less nutrient loss from erosion, and less damage to young stands from excessive runoff during heavy rains. Yields on terraced land were further adjusted, downward in this case, to reflect the area lost from cultivation due to the grassed backslope of the terrace ridges. Thus the per acre yield incorporates the total acreage terraced including the grassed backslope. The yield estimates used for the different cropping activities in the model are summarized in Table B.9.

Land Base

The land resource base for agricultural production in the model makes up the final segment of the physical data set. As mentioned briefly in Chapter III, the tillable land and pasture land comprising the resource base are classified into 12 land class categories according to the slope of the land. The source for this classification which is described in Table B.10, was a USDA computer tape developed at Iowa State University from the data obtained during the 1967 Conservation Needs Inventory of Iowa (Iowa CNI). In compiling this inventory, approximately two percent of the land from each township in a county was sampled and the observations were classified according to land class and land use.

In developing the land base for the model, all the sample points from a county which fell within the river basin boundaries were retrieved from the computer tape. For the portion of each county lying in the river basin, the amount of land falling in each land class and the use to which the land was committed was then extrapolated from these sample points. In the case of one county, Guthrie, the collection of sample plots did not contain any points that were in the river basin. Rather than omit this area from the land base, four sample plots, all lying within approximately a mile of the river basin boundary, were used to represent the Guthrie acreage lying in the basin.

Data were available from an as yet unpublished report entitled, "Potential Cropland Study," which contains a 1975 update of the 1967 land use data [99]. The study was conducted by the Statistical Laboratory at Iowa State University under contract with the Soil Conservation Service of the U.S. Department of Agriculture. It would have been desirable to use the more recent data on land use gathered during this resurvey. However, the resurvey, which was designed for regional and national estimation, contains only a subset of the original sample space and, therefore, has low reliability for predicting changes in land use at the state level due to the small number of observations from each state. For this reason, the land use as indicated by the more statistically reliable 1967 inventory was used in the model with one adjustment to be explained below. The 1975 Iowa data, while its reliability is uncertain, does indicate that there has been little change in cropland between 1967 and 1975. Total cropland is nearly the same having decreased 1.4% while pasture land has increased 11%.

In the interest of developing a land base which accommodates potential use for cropland rather than merely reflecting the cropland in production at the time of the survey, an adjustment was made in the land data from the CNI tape. An estimate was made of the amount of land committed to permanent pasture at the time of the survey which could be readily converted to crop production. With the forecasted increases in demand for U.S. agricultural output, it is possible that such conversion might take place. To enable the model to simulate this eventuality, these convertible pasturelands were included under tillable land in the land base for the model. The model then had the option of planting these lands to crops or leaving them in hay.

An estimate of the amount of land classified as pastureland in the CNI that could be converted to crop use was based on the "Potential Cropland Study" mentioned earlier. As indicated by the study, some of the pastureland could be converted to cropland only after improvements to the land had been made. Since there is no way to estimate the cost associated with converting these acreages to cropland, they were left in the permanent pasture land base. Only those lands which were listed as having a high or medium potential for cropland and which could be converted without any development expense were considered.

Rather than endow the basin with a greater capacity for crop production than it would realistically have, a conservative estimate of potential cropland was sought. With this objective and the limitations of the state data for Iowa in mind, the potential cropland estimates for Iowa and for the cornbelt, the next largest geographical area that would yield reliable estimates, were examined with the idea of using the smaller of the two figures. The Iowa data indicated that 9.9% of the pastureland[1] could be converted to crops by merely beginning tillage. The corn belt data which includes Iowa, Illinois, Indiana, Ohio and Missouri, showed that 13.1% of the pastureland could be converted. Since a conservative figure for potential cropland was desired, the Iowa figure was rounded to 10% and used to adjust the tillable land figures in the model even though the higher but more reliable cornbelt figure might be more representative of the situation in Iowa. In each land class in the data base the amount of tillable land was increased by 10% of the pastureland and the pastureland figure was correspondingly reduced. These adjusted acreage figures for each land class were the acreages used in developing the land constraints on the model and are reflected in the distribution of available tillable land and pastureland by land class as indicated in Table B.10.

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[1]The pastureland base on which the Iowa and cornbelt percentages were computed excludes F and G land which by assumption cannot be cropped due to the severe erosion hazard.

CHAPTER VI. ANALYSIS OF POLICY OPTIONS FOR CONTROLLING SOIL LOSS AND SEDIMENTATION

For purposes of comparison throughout the analysis, the first simulation was a base run made with no policy constraints on the model. The results of this simulation and all subsequent simulations are reported in Tables C.1 through C.12.

Base Run

In the base run the model opted for continuous row crop production along with meeting the historical production of hay and the nursecrop oats. The hay and oats were produced on the steeper cropland, class E and some of class D. The balance of D land was in C-C-S, conventional tillage with fall plowing as was the land in class A1 and A. On class B land, contouring was employed with the same rotation. The slight yield advantage with contouring offset the higher labor and fuel costs which are only a small fraction of total production cost, less than 9%. Minimum tillage was employed on slope C land with contouring. Once again the better yields from contouring, even with minimum tillage, offset the slightly higher cost of contouring.

Total corn production in the basin was 90,690,000 bushels with soybean production of 17,209,000 bushels. The net farm income from all four crops and pasture rental under the normal price-relative amounted to $27,860 per farm. In the other price scenarios, net farm income was $17,080 under the low price-relative and $47,700 under the high price-relative.

These income-generating farm production activities resulted in an average soil loss for the Basin of 20.3 tons per acre. This soil loss is higher than the estimated average of 12 tons for the U.S. [110]. However, the soil type and topography in the Nishnabotna River Basin combine for highly erosive conditions. Furthermore, the prevailing agricultural practice in the simulation was continuous row crop. The estimated soil loss in the model is in line with Pinmentel's estimate of average soil loss for continuous corn of 20 tons per acre [73, p. 151]. With a delivery ratio of .25, this soil loss resulted in a stream sediment load from agricultural sources of 9650 mg/liter. This result compares favorably with the long run average sediment concentration of 10,600 mg/liter observed for the Nishnabotna River at Hamburg, Iowa over the period 1940-1963 [81, p. 142]. This close approximation to the observed value for the river basin indicates that the calibration of the physical relationships in the model is acceptable. Interestingly, this sediment load estimate for the base run also aligns closely with the estimates provided by two earlier studies of the Nishnabotna River Basin. The Seay model [81, p. 82], estimated the sediment load to be 10,530 mg/liter in an unconstrained base run simulation. In a similar run, the Jacobs model estimated the sediment concentration to be a little over 10,000 mg/liter [51, p. 112].

In summary of the base run, it is evident that in the absence of government environmental programs, there were only moderate efforts at voluntary soil conservation. The profitability of intensive row crop cultivation resulted in the predominant choice of land depleting technologies specifically, continuous row cropping with the ascendent tillage method being conventional till with fall plowing. The obvious result of this choice of tillage system is high soil loss in the basin and low water quality. While an average soil loss of 20.3 tons per acre is alarming, the loss on some of the lands in the simulation exceeded 60 tons per acre.

Regulatory Policy Analysis

Ban on fall-plow

The policy analysis began with the simulation of the regulatory policies which are reported in Tables C.1 through C.3. The first of the regulations analyzed was a ban on fall moldboard plowing. This simulation produced some potentially useful results for policy formulation. The ban on fall plowing resulted in the adoption of minimum tillage with a 50% reduction in average soil loss and only a slight decrease in net farm income. Under the fall-plow ban, soil loss averaged 10.0 tons per acre and the stream sediment load, with a delivery ratio of .25, was 4760 mg/liter. The net farm income was $27,240 under the normal price-relative for a decline of 2.2% below the base run figure. For the low price-relative and high price-relative scenarios, the decrease in net farm income was 2.2% and 2.3% respectively. The small income penalty associated with the ban on fall-plow indicates that conventional tillage in the fall enjoys only a slight profit advantage over minimum tillage, which entered the solution under a fall-plow ban.

The farmer's choice of technology under the fall-plow ban was decidedly land-conserving with the adoption of minimum tillage on all lands except hayland. In addition, contouring was employed on classes B and C because of the slight yield advantage. The important conclusion to be drawn is that while conventional tillage in the fall may offer slightly higher profits than minimum tillage, mintil may be able to compete favorably with conventional tillage in the spring under a fall-plow ban.

Of particular importance is the relatively small decrease in net farm income associated with the sizable decrease in soil loss under the policy to ban fall moldboard plowing. It appears that serious objections to the ban on the basis of lost income might not be justified.

While the 50% reduction in soil loss under the fall-plow ban is significant, the average soil loss figure of 10 tons per acre is still well above allowable levels recognized by the Soil Conservation Service. The reason soil loss was still excessive with minimum tillage is due to the intensive row crop cultivation (C-C-S) pursued on all lands excluding hayland, even on steep slopes. Terracing does not enter the solution because of the higher cost associated with that practice. The still excessive soil loss figure notwithstanding, the potential of the ban on fall moldboard plowing for reducing soil loss without a significant income penalty has been clearly indicated by the model. This ban may be employed in conjunction with other policies, some of which combinations will be evaluated in the following section and in subsequent sections.

Ban on fall-plow and straight-row cultivation

In the third simulation, the ban on fall-plow was combined with a ban against straight-row cultivation on slopes with more than a 2% gradient. The policy combination was very effective in cutting soil loss which fell to an average of 2.1 tons per acre. The contribution to stream sediment load from the agricultural activities in the simulation was 900 mg/liter. The highest soil loss for a single activity in the solution was just over 5 tons per acre for C-C-S with minimum tillage on class C land. This reduction in soil loss was accomplished without a drastic fall in net farm income. Under the normal price-relative scenario, net farm income with this policy combination was $25,880 for a decrease of 7.2% below the base run income figure. Under the low price-relative scenario net farm income decreased 9.6% below the base run to $15,350; while under the high price-relative, net farm income was $45,060 or 5.5% below the base run.

The farmer's choice of technology under the ban on fall-plow and straight-row cultivation was strongly land-conserving. Minimum tillage was employed on all land except hayland with contouring also used on slopes B and C. On class D land, terracing was used in conjunction with mintil since straight-row cultivation was forbidden. Crop production was maintained within 98% of the base production for soybeans and within 96% of the base for corn.

An interesting aspect of the policy to ban fall-plow and straight-row cultivation is that the highest soil loss from any activity in the solution is in the neighborhood of 5 tons per acre. This combined policy could be used as a substitute for an outright limit on soil loss of 5 tons per acre, the level which is currently specified under Iowa's

Conservancy District Act of 1971. A more explicit comparison will be made in the discussion of the soil loss limit policy.

Ban on straight-row cultivation

In the fourth simulation, a solitary ban on straight-row cultivation on slopes over 2% was examined. With fall plowing allowed under this policy, soil loss increased to 4.1 tons per acre on the average. The contribution to the stream sediment load was 1790 mg/liter. Under this less restrictive ban, corn production was 99% of the base run level and soybean production was maintained at 97% of the base production. As a result, net farm income decreased only 5.3% below the base run income level under the normal price-relative scenario. The decrease in income under the low price-relative and high price-relative scenarios was 7.9% and 3.6% respectively.

Continuous row crop activities (C-C-S) were selected on all land except slope E where hay was grown and on 66,400 acres of D land where the heavy hay rotation C-O-M-M-M-M was selected. On the majority of D land, 446,700 acres, corn and soybeans were grown in the rotation C-C-S with conventional tillage and the slopes were terraced. Minimum tillage was used for the row crops on C land along with contouring. The row crops on B land were also planted on the contour but conventional tillage was used. While overall soil loss of 4.1 tons per acre was within the allowable limit of 5 tons per acre with thise choice of technology, the highest soil loss occurred on class B land where the loss was 6 tons per acre. The soil loss on C land was just over 5 tons as it was with C-O-M-M-M-M on D land. If slightly relaxed standards of 6 to 7 tons per acre were acceptable, then a singular ban against straight-row plowing on slopes could serve as a substitute for a soil loss limit regulation.

Soil loss limit of 5 tons

A comparison with the soil loss restriction policy of 5 tons per acre was made during the fifth simulation run. Only those activities which result in a soil loss of 5 tons per acre or less were allowed in the feasible set. This simulation is of particular interest because it replicates an Iowa statute which became effective in 1971.

Under the Iowa Conservancy District Act, farmers and others are responsible for conservation of soil and water resources. In addition to establishing a formal conservancy policy, the act specifically provides for regulations limiting soil loss due to erosion. On agricultural lands, the allowable annual soil loss ranges from 1 to 5 tons per acre depending on the soil type. The maximum soil loss permitted on Marshall soil is 5 tons per acre per year. In the event that soil loss in excess of the limit results in a nuisance to other property owners in the area, the local Soil Conservation District Commissioner is charged with securing voluntary abatement of the nuisance by the landowner who is in violation of the limit. A failure on the part of the landowner to adopt the needed erosion control practices would result in a district court order to obtain immediate compliance with the soil loss limit. Any continued violation could bring a finding of contempt of court.

The economic effect of this 5-ton soil loss restriction in the Basin was simulated by the model. Land conserving technologies were selected for slopes B through E, to include minimum tillage, contouring and/or terracing. On the flatter slopes, A and Al, conventional tillage with C-C-S was still allowed in the solution since this activity satisfied the soil loss restriction on these gentle slopes. All conventional tillage activities were accomplished with fall plowing. Crop production was maintained at 96% of the base run level for corn and soybeans under the normal price-relative.

Under the normal price-relative scenario, net farm income fell 9.5% below the base run level. The decline was 13.5% and 6.8% under the low price-relative and high price-relative scenarios. Under all scenarios, the income penalty was significantly larger than with the ban on straight-row cultivation and moderately larger than the income penalty with the combined ban on straight-row cultivation and fall-plow. With the soil loss restriction resulting in an average soil loss of 2.5 tons per acre, it is noteworthy that the combined ban resulted in a slightly lower average soil loss with approximately the same crop production levels and a smaller income penalty.

Soil Loss Tax Analysis

In this phase of the analysis, the soil loss tax is evaluated. This tax would be calculated on the basis of soil loss in tons per acre per year. Since it would be impossible to physically measure the amount of soil loss on each farm, a more readily observable basis for the tax must be found for policy implementation. The tax levy would have to be specified for a particular area in terms of each crop activity on each slope and type of soil, taking into consideration any conservation practice employed. The amount of the tax charge for each particular cropping situation could be calculated using the soil loss estimate from the universal soil loss equation. For purposes of administration, then, the tax would be specified in terms of the particular crop activities, but the indirect basis for the tax would still be the estimated soil loss resulting from each activity. In the interest of clarity throughout this report, the soil loss tax will be discussed in terms of its indirect but actual basis, the estimated soil loss in tons per year.

The alternative tax levels considered, are specified in the model in terms of dollars per ton of soil loss per year. The opportunity for farmers to shift the tax burden either forward to consumers or backward to resource suppliers increases with time. However, the model is not a general equilibrium market model and cannot deal with tax burden shifting. Therefore, policy analysis with the model must be based on one of two possible assumptions: either (1) assume there is no significant tax shifting in which case the tax can be discussed in terms of the dollar tax levy per ton of soil loss; or (2) acknowledge the possibility of shifting in which case the tax must be discussed in terms of the dollar tax burden falling on producers. The actual tax levy would be some larger amount depending on the elasticities of the supplies and demands for crops and inputs. The choice of assumption is arbitrary but the assumption must be made explicit in order to avoid confusion. For simplicity in exposition, the first assumption will be made and thus the terms, tax burden on producers and tax levy, can be used interchangeably.

Since the analysis of the tax is concerned with the different effects of many alternative tax levels, parametric programming was employed in simulating the tax policies. Tax levels of $.10, $.20, $.30, $.40, $.50, $1.00, $1.50, $2.00, $2.50, $3.00, $3.50 and $4.00 were considered under each of the three price scenarios. As would be expected, the soil loss tax became effective in modifying farmer behavior at lower tax levels as the price-relative decreased.

<u>High price-relative results</u>

Under the high price-relative scenario, a tax of $.10 per ton of soil loss had no effect on the crop production pattern or on soil loss as indicated in Table C.5. A tax of $.20, however, affected a change in practices which resulted in a decrease in soil loss from more than 20 tons per acre in the base run to just over 11 tons with an attendant fall in the contribution to stream sediment load to 5330 mg/liter using a delivery ratio of .25. With the $.20 tax, net farm income fell to $46,550, a decrease of 2.4% below the base run. The above changes were associated with a modification in the choice of technology on D land. Minimum tillage was adopted in place of conventional tillage for the rotation C-C-S. This switch to a soil conserving practice resulted in only a 1.4% decrease in corn production.

A tax of $.30 resulted in the adoption of contouring with C-C-S on A land but since class A land is not very erosive there were no significant changes in soil loss or sedimentation nor in crop production. Net farm income decreased further by \$360. Increasing the tax to \$.40 and then \$.50 produced no changes other than to reduce net farm income.

At the \$1.00 level, however, the tax induced a decrease in soil loss to 3.9 tons per acre with sedimentation of 1700 mg/liter. Even with this sizable decrease in soil loss, production was still maintained at more than 98% of the base level for corn and soybeans. Net farm income declined to \$44,730 or 6.2% below the base level. An even larger income penalty might be expected with the tax level at \$1.00 but because the soil loss dropped so dramatically, the income decline was modest. This tax-motivated soil conservation was realized by the use of terracing on D land with conventional tillage for the rotation C-C-S.

A further decrease in soil loss to 2.1 tons per acre was the result of increasing the tax to \$1.50. The stream sediment contribution at this soil loss level was 900 mg/liter. Two land-conserving changes in production practices were responsible for this cut in soil loss: (1) the switch from conventional tillage with contouring on B land to minimum tillage with contouring and, (2) the adoption of minimum tillage on the terraced land in class D. There was a slight decrease in corn production to 87,600,000 bushels due to the adoption of minimum tillage on these lands. In spite of the low level of soil loss achieved, net farm income was only 7.1% below the base level.

A further increase in the tax to \$3.00 per ton of annual soil loss motivated the employment of minimum tillage with contouring on land class

B but realized only a slight decrease in soil loss to 2.0 tons per acre on the average. Increases in the tax to \$3.50 and \$4.00 brought no further savings in soil loss.

Overall, in the high price-relative scenario, a tax on soil loss appears to be an effective instrument for inducing soil conserving technology without imposing an unbearable income penalty. Important changes in farming practices which resulted in significant reductions in soil loss occurred with tax levels of \$.20, \$1.00, and \$1.50. A tax of \$1.50 was capable of achieving a slightly lower level of average soil loss than the policy to limit soil loss to 5 tons per acre with an income penalty of \$100 more.[1] A tax level greater than \$1.50 per ton did not appear to be justified.

Normal price-relative results

The soil loss tax was slightly more effective in controlling erosion under the normal price-relative, in that management practices were modified at lower tax levels and changes occurred more abruptly. The reason, of course, is that a given tax level is larger relative to net farm income under the normal price-relative. By imposing a greater relative burden, a given tax level provides a greater impetus to alter practices in order to avoid the tax.

At \$.10, the first tax level imposed on the model, the response was an abrupt decrease in average soil loss to 11.2 tons per acre as shown in Table C.6. The effect of this tax was identical to the impact of the

[1]Compare line 8 in Table C.5 with line 5 in Table C.1.

$.20 tax in the high price-relative scenario. The reduction in soil loss was accomplished by converting to minimum tillage on land class D with a 1.4% decrease in corn production and a 2.2% decline in net form income.

A tax of $.30 brought in contouring on A land but the choice of tillage method remained contil and there were no significant changes in production or soil loss. Increasing the tax to $1.00 produced a marked decline in soil loss to 2.1 tons per acre with a stream sediment contribution of 900 mg/liter. As with the $1.50 tax in the preceding scenario, this measure of control over erosion was realized by selecting minimum tillage with contouring on B land and the introduction of terracing on D land with minimum tillage. Net farm income with a soil loss tax of $1.00 decreased 9.1% below the base level. In percentage terms this loss in income is greater than the income penalty imposed with the same decrease in soil loss under the high price-relative.

Further increases in the tax up to the $4.00 level brought no noteworthy reductions in erosion. In the normal price-relative situation just analyzed, the significant tax levels for curtailing soil loss were $.10 and $1.00.

Low price-relative results

The impact of the soil loss tax in the low price-relative scenario summarized in Table C.7, parallels the results under the normal price-relative closely except that the notable tax levels for reducing erosion were $.10 and $.50. Otherwise, the response in production levels, choice of technology and resulting soil loss and sedimentation were identical.

The implementation of the \$.10 tax under the low price-relative brought a 3.0% decrease in net farm income as the price for cutting soil loss to 11.2 tons. Attendant with the decrease in soil loss to 2.1 tons which was motivated by the tax of \$.50, was a decline in net farm income of 11.0% below the base level. The percentage income penalties were largest under this low price-relative scenario because of the smaller base for net farm income.

Increases in the tax to \$1.50 and above resulted in E land being withdrawn from crop production. With low crop prices and comparatively high soil loss tax levels, the idling of this highly erosive but relatively unproductive land is not surprising. The land probably would be used for permanent pasture. While the action further reduced soil loss slightly to the neighborhood of 1.9 tons per acre, the resulting loss of production and net farm income do not warrant the slight gain in erosion control. Under the low price-relative in the model, soil loss taxes above \$.50 per ton do not appear to be justified.

In none of the cases did the tax induce a shift from fall-plow to spring-plow. Soil losses are less with spring-plow, so that a tax on soil loss could provide the incentive to switch to this tillage practice. However, the costs associated with spring-plow were sufficiently higher and the yields sufficiently lower than fall-plow, that as the increasing tax made soil loss more costly, a more profitable alternative than spring plow always entered the solution, either minimum tillage or contouring with fall-plow.

Under all three price scenarios, the tax on soil loss proved to be an effective policy option for controlling erosion. Soil loss levels comparable to those realized under regulatory policies could be achieved with roughly the same income penalty. While taxes are never popular, they do allow a degree of choice which is not present with an outright ban on selected production practices.

Soil loss tax with ban on fall-plow

This next simulation was considered to see if there would be any advantage to combining the soil loss tax with a ban on fall-plow. As Table C.7 indicates, in the normal price-relative scenario, the combined ban and tax produced the same results for tax levels of $.10 to $.50 as did the ban alone. Soil loss was cut in half to 10.0 tons per acre on the average. This degree of erosion control was only marginally better than that realized with a tax of $.10 alone which resulted in a soil loss of 11.2 tons per acre. It is evident that for purposes of cutting soil losses approximately in half, either policy alone is roughly as effective as the combination of a tax and a ban on fall-plow.

Increasing the tax to $1.00 in conjunction with the fall-plow ban reduced soil loss to 2.0 tons per acre which was just under the 2.1 ton level realized with a tax of $1.00 alone. The slightly better erosion control gained with the combined policy is not significant enough to warrant selection of the combined policy over the tax alone. With the tax levied at $1.50 and above, the ban in conjunction with the tax produced the same results as the tax by itself.

The model indicates that nothing of significance is gained by combining a ban on fall-plow with a soil loss tax. For moderate reductions in soil loss to the neighborhood of 10 tons per acre, either a ban on fall-plow by itself or a tax on soil loss alone of \$.10 will be about equally effective. Even a comparison of net farm incomes does not give reason for choosing either solitary policy over the other. A tax of \$.10 by itself resulted in a net farm income of \$27,250 while the ban alone resulted in a figure of \$27,240. For reductions in soil loss to the neighborhood of 2 tons per acre, the simpler tax policy alone probably would be preferable to the combined policy especially since net farm income is \$130 higher at the \$1.00 tax level under the tax policy alone.

These same conclusions apply in the low price-relative scenario except that the reduction in soil loss to the range of 2 tons per acre occurs at a tax of 50¢ rather than a \$1.00 with both the solitary tax policy and the policy combining a tax with a ban on fall-plow. The conclusions regarding the relative merits of the policies are identical.

In the high price-relative scenario, the above conclusions apply for moderate reductions of soil loss to around 10 tons per acre. For a further decrease in soil loss to around 2 tons per acre a slightly different comparison emerges under the high price-relative, although the final conclusion will remain unchanged. The combined policy achieved the 2-ton soil loss level with a tax of \$1.00 whereas the tax policy alone required a tax of \$1.50 to reduce soil loss to 2.1 tons per acre. However, even with a higher tax level under the solitary tax policy, net farm income is only \$110 less than under the combined policy. This result seems paradoxical especially since soil loss also is slightly higher with the solitary tax.

The explanation is found, however, in the choice of activity on land classes A and A1. With the singular tax policy, conventional tillage was selected for growing C-C-S. Under the combined policy the same rotation was employed but minimum tillage was adopted. The application of mintil technology explains the slightly lower soil loss but there is also a yield penalty for corn, hence net farm income was only $110 higher than with the tax policy alone. Even though the combined policy achieves the 2-ton soil loss level with a slightly smaller income penalty, whether the extra $110 in income justifies the more complicated dual policy over the soil loss tax by itself could be challenged.

Subsidy Policy Analysis

Contour subsidy

In this third section of the analysis, subsidies are evaluated as policy instruments for encouraging land-conserving management practices. The subsidies were granted on a per-acre basis for those acres that were managed in accordance with the subsidized practice. The first policy considered was a subsidy to encourage contouring. As discussed in Chapter II, contour farming is effective in controlling erosion on moderate slopes. The subsidy for contouring, however, did not prove to be an effective policy for reducing soil loss as indicated in Tables C.1 through C.3. The reason is that contouring is not effective on slopes much over 7% and therefore was not capable of reducing average soil loss for the river basin below

20.2 tons per acre. Another reason for the insignificant decrease in soil loss with the contour subsidy is that in the base run, contouring had been adopted already on two of the three land classes on which it can be effectively employed. Contouring was used with conventional tillage for C-C-S on land class B and again with minimum tillage on C land. The profitability of contouring, particularly on slopes of moderate steepness where this practice is most effective, was sufficient to ensure its adoption on these lands. While there are higher labor and fuel costs associated with contouring due to the formation of point rows [73], yields are sufficiently higher as a result of controlling soil and nutrient loss and from greater infiltration of water [80], that contouring was capable of paying its own way on lands between 3% and 7% slope. Because of the formation of point rows, however, the profitability of contouring would diminish if larger equipment with narrower rows were adopted.

A subsidy of $.60 per acre was able to bring in contouring on A land also, where conventional tillage was used for the row crop rotation, C-C-S. The application of contouring on A land resulted in an almost imperceptible decrease in soil loss and a measurable but insignificant decrease in sediment load from 9650 mg/liter to 9630 mg/liter. This very slight decrease in soil loss, is not worth the expenditure on the subsidy which was $402,200 for 670,390 contoured acres on land classes A, B and C. In the absence of the subsidy, 640,280 acres would have been contoured anyway. In short, the contouring subsidy had a negligible impact on soil loss.

Minimum tillage subsidy

The second subsidy policy evaluated applied to minimum tillage crop activities. Based on the results of this ninth simulation, the mintil subsidy offers more promise as an erosion control measure than the preceding subsidy, although there are limits on the effectiveness of the mintil subsidy as well. For a basis of comparison in evaluating the mintil subsidy, recall the base run simulation. In the absence of the subsidy, minimum tillage technology was adopted only on slope C land. Conventional tillage with fall plowing proved to be more profitable on the other land classes.

Introducing the subsidy in the normal price-relative scenario indicated that subsidization began to influence the farmer's choice of mintil technology at the subsidy level of $2.70 per acre. At that level, the subsidy encouraged the switch to mintil with contouring on B land in place of conventional tillage. The effect on soil loss was not very great, however, as B land possesses about average erosion hazard and had been contoured prior to the subsidy. The soil loss on this land in the absence of the policy was only 6 tons per acre. Thus, the adoption of mintil on B land only reduced average soil loss for the basin from 20.3 tons per acre to 19.2 tons. The contribution to stream sediment load decreased slightly to 9100 mg/liter. Net farm income with the subsidy at $2.70 was $27,970 or less than .5% greater than net farm income at the base run level. Corn production declined slightly because of the conversion to mintil but was still more than 98% of the base production. Total subsidy payments under the policy amounted to $1,728,737 or $335 per farm.

Increasing the subsidy to $2.90 an acre brought about a major reduction in soil loss to 10.1 tons per acre along with a reduction in sediment load to 4780 mg/liter. Net farm income with this subsidy was up .5% above the base level to $28,000. This amount includes $619 in subsidy payments. The total cost of the program to the government was $3,190,873. The nearly 50% reduction in soil loss was realized as a result of the application of minimum tillage for the acreage planted in C-C-S on D land. Corn production decreased by 1.2 million bushels but production was still 97% of the base level.

A further increase in the subsidy to $3.00 per acre completed the adoption of minimum tillage on cropland with the application of mintil on class A and Al lands. Only a slight decrease in soil loss to 10.0 tons per acre was gained. The incremental cost of the subsidy bill was $836,564. It is not likely that policy makers would consider this cost warranted by the negligible decrease in soil loss. It appears that the optimal subsidy level under the normal price-relative is $2.90 per acre resulting in a 50% reduction in soil loss below the base run figure.

The effective subsidy levels varied considerably under the other price-relatives. The response pattern to the subsidies under the different price relatives was identical, but the changes in production occurred for different subsidy values depending on the scenario.

Under the high price-relative, the first effect of the parametrically increased subsidy was the conversion to mintil on B land which occurred at the subsidy level of $4.80. As under the normal price relative, the decrease in soil loss was slight, a decline to 19.2 tons per acre. Crop production also was identical with the preceding scenario. The total subsidy paid was larger, of course, amounting to $3,073,310 or $596 per farm, not quite double the subsidy payment that produced the same change in management practice under the normal price-relative. The net farm income with this subsidy was $47,880.

The reduction in soil loss to 10.1 tons per acre was achieved under the high price-relative at a subsidy of $4.90. The reduction was realized as a result of the employment of minimum tillage on land class D and crop production was the same as in the preceding scenario. The average subsidy payment to each farm at this level was $1,046 resulting in a net farm income of $47,900.

An increase in the subsidy to $5.00 per acre coaxed the adoption of mintil on land classes A and A1. As before, the reduction in soil loss was negligible, probably invalidating the $5.00 subsidy in the eyes of policy makers.

The downward step in soil loss to 19.2 tons per acre occurred in the low price-relative with a subsidy of $1.60 per acre. The choice of technology and resulting crop production levels were identical with the previous two scenarios. The net farm income was $17,140, $199 of which was in the form of subsidy payments.

The 50% decrease in soil loss under the low price-relative was accomplished with a subsidy of \$1.70 per acre. This reduction was realized, as before, by the adoption of minimum tillage on land class D. The total subsidy expenditure was at its lowest level under the low price-relative in the amount of \$1,870,512 or \$363 per farm. The net farm income was \$17,160. As in the previous scenarios, a higher subsidy would provide the incentive for the use of minimum tillage on land classes A and A1 but the insignificant decrease in soil loss probably would not warrant the higher payment. In the low price-relative, it appears that the optimal subsidy level for controlling erosion would be \$1.70 per acre.

As revealed by the analysis of all three price scenarios, a subsidy on minimum tillage activities is effective in reducing soil loss to around 10 tons per acre. Lower soil loss levels cannot be induced by a mintil subsidy because if row crops are involved, minimum tillage by itself cannot control soil loss within acceptable levels on slopes in excess of 5%. A mintil subsidy then, is effective for reducing average soil loss by about 50% but cannot be used alone to achieve a greater degree of erosion control.

Redundant Policy Combinations

Some additional policy combinations that were evaluated but rejected because of major disadvantages under the cost-price relationships in the model are mentioned briefly:

1. Subsidy for contouring combined with a ban on fall moldboard plowing. The ban alone was responsible for most of the erosion control by

bringing in mintil with contouring on land classes B and C along with minimum tillage on the other cropland. The subsidy in combination with the ban encouraged the application of contouring on A land as well but the reduction in soil loss was very slight. The ban alone resulted in a soil loss of 10.05 tons per acre. The ban in combination with a subsidy of $.40 realized a soil loss of 10.03 tons per acre in the normal price-relative. The contouring subsidy did not add a significant degree of erosion control. The ban on fall-plow alone would be a better policy option.

2. Subsidy for minimum tillage combined with a ban on fall mold-board plowing. A mintil subsidy could not be meaningfully combined with a fall-plow ban in the model because the ban alone resulted in the use of minimum tillage on all cropland. The subsidy would be redundant in such a policy combination.

3. Combined subsidy on mintil activities and contour activities. The combined subsidies are no more effective than the subsidy on mintil alone. A review of the policy simulations indicates that, in order to reduce soil loss to the neighborhood of 10 tons per acre, mintil with contouring must be employed on both B and C lands with minimum tillage also used on land class D. Under the normal price-relative a mintil subsidy alone of $2.90 per acre was sufficient to induce the required changes in management practices.

CHAPTER VII. SUMMARY, CONCLUSIONS AND FURTHER RESEARCH NEEDS

Summary and Conclusions

The results of the analysis in Chapter VI indicate the equivalence of certain policies in reducing soil loss. The analysis also reveals that certain policy combinations which might have been considered for implementation would be redundant. One or the other of the policies alone would have approximately the same effect as the policy combination. The following paragraphs summarize the results of the analysis and draw conclusions regarding the policy options for controlling soil loss and sediment pollution.

Conventional tillage with fall plowing appears to offer a slight profit advantage over minimum tillage. However, minimum tillage may be able to compete with conventional tillage employing the spring-plow option. A ban on fall moldboard plowing, therefore, would be expected to encourage the adoption of minimum tillage and result in a reduction in soil loss and sedimentation to levels comparable to the 50% reduction realized in the model.

A dual ban on fall plowing and straight-row cultivation on slopes over 2% appears to be as effective as a soil loss limit of 5 tons per acre in reducing soil loss and sedimentation. In fact, the dual ban was slightly more effective although not significantly so. The dual ban resulted in slightly higher income levels, around 2% to 4% depending on the price scenario. Since the soil loss limit requires the estimation of annual soil loss, the dual ban would be easier to administer. For these reasons the dual ban might be preferred over a 5-ton soil loss limit by policymakers. If slightly relaxed soil loss standards in the neighborhood of 6 to 7 tons per acre could be tolerated, a singular ban against straight-row plowing on slopes over 2% might be an effective policy choice.

The further equivalence, in terms of reducing soil loss, between a tax on soil loss, a 5-ton soil loss limit, and a dual ban on fall-plow and straight-plow plowing is indicated by the analysis. Based on the comments in the last paragraph the policymaker's choice would probably be between the tax and the dual ban. The dual ban resulted in 1.5% to 2.0% more income but the tax allows farm operators more freedom in choosing crops and management practices. Policymakers must weigh the tradeoff between income and freedom of choice.

There is another consideration in the choice between these two policies. If the goal were primarily to reduce sediment pollution of surface waters, the tax policy offers the possibility of achieving the objective at the lowest cost, the lowest income penalty. Under a soil loss tax, the farm operators could choose to curtail those activities where the soil loss per dollar of income earned was the highest. In this way the desired reduction in sedimentation from soil erosion could be achieved at the smallest sacrifice in income. While controlling total soil loss and sedimentation, that strategy could still result in excessive soil loss on some land classes. Farmer's might choose to produce on moderately sloped lands, classes B and C, with high-profit row crop activities resulting in excessive soil loss per acre but in order to reduce total soil loss and sedimentation within limits they might curtail row crop production on the highly erosive but marginally productive steeper lands. In this way a standard for suspended sediment in a river basin could be achieved by means of a soil loss tax but the productivity of the moderately sloped lands might be depleted through excessive soil loss over time. Therefore, if the objective instead were to preserve the productivity of the land by reducing soil loss on all land classes to tolerable levels, enforcement of a ban on highly erosive practices or an outright soil loss limit could guarantee that soil loss would not exceed the allowable limits on any land class. Perhaps the combined objective of preserving the productivity of the land and reducing sediment pollution could best be achieved by a ban rather than a tax on soil loss.

A ban on fall moldboard plowing combined with a soil loss tax appears to be a redundant policy combination. For reductions in soil loss and sedimentation by 50%, either policy alone would accomplish the objective. For reductions of 90%, the tax alone is effective. Adding the ban on fall-plow in combination with the tax is superfluous. The ban by itself is not capable of achieving the 90% reduction in soil loss and sedimentation.

A subsidy for contouring appears to be of no benefit in significantly reducing soil loss because contouring is not effective on the steeper, highly erosive slopes. A subsidy on minimum tillage seems to be capable of reducing soil loss and sedimentation by 50%. At that point minimum tillage is in use on all erosive lands and no further reductions can be realized.

The results of the analysis suggest that the following policy combinations are also redundant.

1) Subsidy for contouring combined with a ban on fall moldboard plowing. The ban on fall-plow alone is for all practical purposes as effective in reducing soil loss as the combined policy.

2) Subsidy for minimum tillage combined with a ban on fall moldboard plowing. The subsidy adds nothing to the erosion control provided by the ban alone.

3) Combined subsidy for minimum tillage and contouring. The combined subsidies are no more effective in curtailing soil loss than the subsidy for minimum tillage alone.

A survey of all the simulation results indicates that policies can be grouped according to a two-tier effect in reducing soil loss and sediment pollution in the river basin. One group of policies appears to be effective in reducing soil loss by 50% and another group by 90% as indicated in Table 6.1. There were a few intermediate results such as with the ban on straight-row plowing which reduced soil loss to 4.1 tons per acre. Some tax and subsidy levels also produced intermediate soil loss reductions but by and large the two-tier effect was very evident.

Apparently the two-tier effect was due primarily to a change in crop management practices on land class D. This land class which contains slopes between 9% and 14% is highly erosive and contains 31% of the land

Table 6.1. Policy effectiveness groups

Policy	Average soil loss (tons per acre)
50% Reduction in soil loss and sedimentation:	
Ban on fall-plow	10.0
Soil loss tax 10¢ (low P-R)	11.2
Soil loss tax 10¢ (normal P-R)	11.2
Soil loss tax 20¢ (high P-R)	11.2
Mintil subsidy $1.70 (low P-R)	10.1
Mintil subsidy $2.90 (normal P-R)	10.1
Mintil subsidy $4.90 (high P-R)	10.1
90% Reduction in soil loss and sedimentation:	
Ban on fall-plow and straight-row plow	2.1
Soil loss limit of 5 tons/acre	2.5
Soil loss tax $.50 (low P-R)	2.1
Soil loss tax $1.00 (normal P-R)	2.1
Soil loss tax $1.50 (high P-R)	2.1

in the river basin. Further research should reveal whether this result will generalize to other river basins containing a large class of erosive land. The two-tier effect was observed in all price scenarios, lending support to the generality of this result. For reductions in average soil loss by 50%, the income penalty ranged from 2.2% to 3.0% depending on the policy option and price scenario. Those policies which succeed in cutting average soil loss by 90% in the model are of interest because they approximate the degree of erosion control specified by the

Soil Conservation Service, 5 tons per acre or less. The 5-ton soil loss limit, the dual ban on straight-row plowing and fall-plow, and the soil loss tax achieved this standard and in the process reduced net farm income from 5.5% to 13.5% depending on the price scenario.

To the extent that the crop yield and cost estimates and the physical coefficients in the model accurately reflect the reality of agricultural production and to the extent that farmers attempt to maximize net income, the simulation results suggest that soil loss in the Nishnabotna River Basin and in similar river basins may be controllable within approximately 5 tons per acre with moderate income penalties on the average for farmers. These reductions in soil loss would be accompanied by corresponding reductions in the agricultural contribution to stream sediment load thus helping to control a major cause of degraded water quality. These results assume that the evaluated policies can be enforced. Additional research needs to be conducted with the aid of political scientists into the feasibility of administering the alternative policy options. Finally, it should be noted that actual income penalties resulting from the policy options could be higher than estimated to the extent that the optimal management practices assumed in the model are not employed.

Further Research Needs

A notable characteristic of research in natural resource issues is its multidisciplinary nature involving the physical, institutional and economic dimensions of the problem. Research by physical and biological scientists determines what is physically or technically possible with respect to resource use. The institutional aspect of the resource problem concerns the delineation of socially acceptable programs for the development and use of natural resources. The policy-maker is guided by lawyers, sociologists, and political scientists in discerning the boundaries imposed by the legal system, social values, and the political process. These same social scientists can help initiate institutional change which might facilitate the achievement of societal objectives for resource use. Finally, economists determine what is economically desirable from among the technically feasible and socially acceptable alternatives.

Several specific areas in this interdisciplinary research effort require further investigation. Despite extensive research on the mechanics of soil transport this complex procedure eludes complete understanding. Hopefully, further research can illuminate the physical relationships clearly enough to allow modeling of the transport process to replace the sensitivity analysis which was used in this study with several hypothesized values for the delivery ratio.

Lack of definitive findings on the nature of the physical and chemical interactions between, sediment, and agricultural chemicals precluded the inclusion of chemical pollutants in this investigation. While sediment pollution poses a serious threat to the quality of surface water, this source of pollution is but one part of a broader environmental problem which involves pollution by fertilizers and pesticides. These pollutants all originate in runoff from agricultural lands but until their dynamic and complex chemical equilibria are understood it is difficult to estimate the response of the pollutants to remedial policies.

Further research is also needed into the comparative yields realized with crops managed under minimum tillage technologies. While minimum tillage offers significant reductions in soil loss, this technology is not likely to gain widespread adoption unless favorable yields and costs can be clearly documented which indicate that net returns from minimum tillage are at least comparable with those from conventional tillage.

In the area of political science, investigation into the administrative difficulty of implementing and enforcing the alternative policies is needed. It is possible that a policy which is technically feasible and economically desirable may be impractical from an administrative standpoint.

With respect to further economic research in the area of resource and environmental policy simulation, two extensions of this analysis are suggested. First, to assess the distributional impacts of alternative policies, this model could be enlarged to incorporate several representative farm units rather than one typical farm for the river basin. By modeling several farms to capture differences in farm size and income as well as differences in composition of farm acreage by land class, the incidence across farms of the benefits and costs of alternative policies would be illuminated. Second, to determine how farmer responses might differ in the long run, a dynamic multi-period model might be constructed. This revised model could be useful in analyzing long-run policy impacts if it incorporated the cumulative effect of erosion in degrading soil productivity. These extensions of the analysis would amplify and qualify the results reported in this study, increasing the knowledge available for policy formulation.

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APPENDIX A

Table A.1a. Equipment cost, annual ownership cost, and repair cost for C-C-S rotation with conventional tillage and spring-plow[a]

Equipment	Quantity	Size	Initial cost 1974[b]	Ownership cost factor[c]	Annual ownership cost	Repair cost
Tractor (diesel)	1	125 PTO	$19,730	.17342	$3421.58	$492.66
Tractor (diesel)	1	70 PTO	11,830	.17342	2051.56	298.12
Moldboard plow	1	6-16"	3,020	.17982	543.06	249.50
NH_3 applicator	1	7 knife	2,035	.17982	365.93	48.14
Tandem disk w/herb and insect attach.	1	20'	4,705	.17982	846.05	61.25
Harrow (spiketooth)	1	30'	460	.17982	82.72	1.51
Planter	1	4-38"	3,400	.17982	611.39	80.88
Rotary hoe	1	4-38"	1,240	.17982	222.98	4.02
Cultivator	1	4-38"	1,470	.17982	264.33	47.67
Combine (self-propelled)	1	95-110 hp	21,600	.17916	3869.86	492.24
Corn head	1	2-38"	2,800	.17982	503.49	73.78
Soybean platform	1	13'	2,500	.17982	449.55	8.25
Grain wagon	2	185 bu	940	.17916	168.41	-[d]
	Cost per 320 acre				$13,400.91	$1858.02
	Cost per 3 acre rotation				$125.63	$17.42

[a] Application of bulk fertilizer (P and K) is custom hired.

[b] Source: [49].

[c] From Table 4.2.

[d] Included in hauling cost, Table A.10.

Table A.1b. Equipment costs, annual ownership cost, and repair cost for C-C-S rotation with minimum tillage[a]

Equipment	Quantity	Size	Initial cost 1974[b]	Ownership cost factor[c]	Annual ownership cost	Repair cost
Tractor (diesel)	1	80 PTO	$15,550	.17342	$2696.68	$388.28
Sprayer (trailer)	1	25'	950	.17982	170.83	5.64
NH_3 applicator (w/coulter)	1	7 knife	2,403[d]	.17982	432.11	56.84
Till planter w/ insecticide attach.	1	4-38"	4,909	.17982	882.74	181.21
Cultivator (disk-hiller)	1	4-38"	1,587	.17982	285.37	47.67
Combine (self-propelled)	1	95-110 hp	21,600	.17916	3869.86	492.24
Corn head	1	2-38"	2,800	.17982	503.49	73.78
Soybean platform	1	13'	2,500	.17982	449.55	8.25
Grain wagon	2	185 bu	940	.17916	168.41	-[e]
		Cost per 320 acres			$9459.04	$1253.91
		Cost per 3 acre rotation			$88.68	$11.76

[a]Application of bulk fertilizer (P and K) is custom hired.

[b]Source: [49].

[c]From Table 4.2.

[d]Includes $368 for seven coulters.

[e]Included in hauling cost, Table A.10.

Table A.1c. Equipment cost, annual ownership cost, and repair cost for C-S-C-O-M-M rotation with conventional tillage and spring-plow[a]

Equipment	Quantity	Size	Initial cost 1974[b]	Ownership cost factor[c]	Annual ownership cost	Repair cost
Tractor (diesel)	1	100 PTO	$18,230	.17342	3161.45	$455.21
Tractor (gas)	1	50 PTO	7,720	.17342	1338.80	192.77
Moldboard plow	1	5-16"	2,590	.17982	465.73	97.70
NH_3 applicator	1	7 knife	2,035	.17982	365.93	33.12
Tandem disk w/herb. and insect. attach.	1	14'	2,540	.17982	456.74	26.00
Harrow (spike tooth)	1	20'	340	.17982	61.14	1.12
Planter	1	4-38"	1,430	.17982	257.14	11.22
Grain drill w/ grass attach.	1	19 tube	1,930	.17982	356.05	6.53
Cultivator	1	4-38"	1,470	.17982	264.34	13.90
Mower conditioner	1	7'	3,475	.17916	622.58	250.35
Rake	1		980	.17982	176.22	35.59
Baler	1	PTO	3,500	.18047	631.65	67.69
Wagon	1	185 bu	940	.17916	168.41	-[d]
		Cost per 320 acres			$8326.180	$1191.20
		Cost per 6 acre rotation			$156.12	$22.34

[a]Custom hire combining and application of bulk fertilizer and insecticide.

[b]Source: [49].

[c]From Table 4.2.

[d]Included in hauling cost, Table A.10.

Table A.1d. Equipment cost, annual ownership cost, and repair cost for C-S-C-O-M-M rotation with minimum tillage[a]

Equipment	Quantity	Size	Initial cost 1974[b]	Ownership cost factor[c]	Annual ownership cost	Repair cost
Tractor (diesel)	1	80 PTO	15,550	.17342	2696.68	388.28
Tractor (gas)	1	50 PTO	7,720	.17342	1338.80	192.77
Sprayer (trailer)	1	25'	950	.17982	170.83	4.60
Tandem disk (oats)	1	14'	2,220	.17982	399.20	7.26
NH_3 applicator (w/ coulter)	1	7 knife	2,403	.17982	432.11	39.10
Till planter with insecticide attach.	1	4-38"	4,909	.17982	882,74	58.62
Grain drill w/ grass attach.	1	19 tube	1,980	.17982	356.04	6.53
Cultivator (disk-hiller)	1	4-38"	1,587	.17982	285.37	12.79
Mower conditioner	1	7'	3,475	.17916	622.58	250.35
Rake	1		980	.17982	176.22	35.59
Baler	1	PTO	3,500	.18047	631.65	67.69
Wagon	1	185 bu	940	.17916	168.41	-[d]
	Cost per 320 acres				$8160.63	$1063.58
	Cost per 6 acre rotation				153.01	19.94

[a]Custom hire combining and application of bulk fertilizer.

[b]Source: [49].

[c]From Table 4.2.

[d]Included in hauling cost, Table A.10.

Table A.1c. Equipment cost, annual ownership cost, and repair cost for C-O-M-M-M-M rotation with conventional tillage[a]

Equipment	Quantity	Size	Initial cost 1974[b]	Ownership cost factor[c]	Annual ownership cost	Repair cost
Tractor (diesel)	1	80 PTO	15,550	.17342	2696.68	$388.28
Tractor (gas)	1	50 PTO	7,720	.17342	1338.80	192.77
Moldboard plow	1	4-16"	1,470	.17982	264.34	14.80
Tandem disk w/ herb. & insect. attach.	1	12'	2,540	.17982	456.743	8.38
Harrow (spike tooth)	1	20'	340	.17982	61.39	1.12
NH_3 applicator	1	7 knife	2,035	.17982	365.94	19.55
Planter	1	4-38"	1,430	.17982	257.14	4.72
Grain drill w/ grass attach.	1	19 tube	1,480	.17982	356.04	6.53
Cultivator	1	4-38"	1,470	.17982	264.34	4.85
Mower conditioner	1	7'	3,475	.17916	622.58	567.61
Rake	1		980	.17982	176.22	88.22
Baler	1	PTO	3,500	.18047	631.65	168.29
Wagon	1	150 bu	725	.17916	129.89	-[d]
		Cost per 320 acres			$7621.75	$1465.12
		Cost per 6 acre rotation			$142.91	$27.47

[a]Custom hire combining and application of bulk fertilizer and insecticide.

[b]Source: [49].

[c]From Table 4.2.

[d]Included in hauling cost, Table A.10.

Table A.2. Depreciation and salvage value factors for equipment [4]

	Remaining Value Equation: n=10 years	Salvage Value Factor	Depreciation Factor (1-S)
Group 1 Implements[a]	$S_1 = 64(.885)^{10}$	$S_1 = .18863$	$d_1 = .81137$
Group 2 Implements[b]	$S_2 = 60(.885)^{10}$	$S_2 = .17684$	$d_2 = .82316$
Group 3 Implements[c]	$S_3 = 56(.885)^{10}$	$S_3 = .16505$	$d_3 = .83495$
Group 4 Implements[d]	$S_4 = 68(.920)^{10}$	$S_4 = .29538$	$d_4 = .70462$

[a] Group 1: Combine, mower-conditioner, wagons.

[b] Group 2: Fertilizer equipment, all tillage tools, rake, all planters, sprayers, combine cornhead, grain platform.

[c] Group 3: Baler.

[d] Group 4: Tractor.

Table A.3a. Machine operating costs and labor costs for corn in C-C-S rotation with conventional tillage on flat land

Operation (Custom apply P & K)	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]
Disk stalks	.09	.099	.50
Plow	.33	.363	1.90
Apply NH_3	.17	.187	.474
1st disk	.09	.099	.70
2nd disk w/herbicide and insecticide	.095[d]	.112[d]	.63
Harrow	.06	.066	.30
Plant	.19	.229	.355
Rotary hoe	.10	.108	.158
1st cultivation	.18	.198	.355
2nd cultivation	.18	.198	.355
Combine	.67	.777	1.263
Total		2.436	6.990

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5].

[d]Field time and labor time adjusted upward by 5% and 13% respectively over first disking for application of chemicals [81, p. 146].

Table A.3b. Machine operating costs and labor costs for soybeans in C-C-S rotation with conventional tillage on flat land

Operation (Custom apply P & K)	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]
Disk stalks	.09	.099	.50
Plow	.33	.363	1.90
1st disk	.09	.099	.70
2nd disk w/herbicide and insecticide	.095[d]	.112[d]	.63
Harrow	.06	.066	.30
Plant	.18	.217	.355
Rotary hoe	.10	.108	.158
1st cultivation	.18	.198	.355
2nd cultivation	.18	.198	.355
Combine	.30	.348	.868
Total		1.808	6.121

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5].

[d]Field time and labor time adjusted upward by 5% and 13% respectively over first disking for application of chemicals [81, p. 146].

Table A.3c. Machine operating costs and labor costs for corn and soybeans in C-C-S rotation with minimum tillage on flatland

Operation	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]
Corn (Custom apply P & K)			
Apply NH_3	.17	.187	.474
Till plant w/ insecticide	.25	.301	.474
Spray pre-emergent herbicide	.098	.108	.10
1st cultivation	.18	.198	.355
2nd cultivation	.18	.198	.355
Combine	.67	.777	1.263
Total		1.769	3.021
Soybeans (Custom apply P)			
Spray contact herbicide	.098	.108	.10
Till plant	.24	.289	.474
Spray pre-emergent herbicide	.098	.108	.10
1st cultivation	.18	.198	.355
2nd cultivation	.18	.193	.355
Combine	.30	.348	.868
Total		1.249	2.252

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5].

Table A.3d. Machine operating costs and labor costs for corn in C-S-C-O-M-M rotation with conventional tillage on flatland

Operation (Custom apply P & K)	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]	Gasoline required gal/acre[c]
Disk stalks	.13	.143	.334	.233
Plow	.36	.396	1.27	.899
Apply NH_3	.17	.187	.316	.210
1st disk	.13	.143	.467	.333
2nd disk w/herbicide and insecticide	.137[d]	.162[d]	.420	.297
Harrow	.08	.088	.200	1.50
Plant	.19	.229	.237	.171
1st cultivation	.18	.198	.237	.171
2nd cultivation	.18	.198	.237	.171
(Custom combine)				
Total		1.744	3.718	2.635

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5], assume operations consist of 2/3 diesel power and 1/3 gasoline power.

[d]Field time and labor time adjusted upward by 5% and 13% respectively over first disking for application of chemicals [81, p. 146].

Table A.3e. Machine operating costs and labor costs for soybeans in C-S-C-O-M-M rotation with conventional tillage on flatland

Operation (Custom apply P)	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]	Gasoline required gal/acre[c]
Disk stalks	.13	.143	.334	.233
Plow	.36	.396	1.27	.899
1st disk	.13	.143	.467	.333
2nd disk w/herbicide and insecticide	.137[d]	.151[d]	.420	.297
Harrow	.08	.088	.200	.150
Plant	.18	.217	.237	.171
1st cultivation	.18	.198	.237	.171
2nd cultivation	.18	.198	.237	.171
(Custom combine)				
Total		1.534	3.402	2.425

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5].

[d]Field time and labor time adjusted upward by 5% and 13% respectively over first disking for application of chemicals [81, p. 146].

Table A.3f. Machine operating costs and labor costs for oats and hay in C-S-C-O-M-M rotation with conventional and minimum tillage on flatland

Operation	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]	Gasoline required gal/acre[c]
Oats (Custom apply P & K)				
1st disk	.13	.143	.334	.233
Apply NH_3	.17	.187	.316	.210
2nd disk	.13	.143	.400	.283
Drill oats w/hay	.22	.265	.233	.167
(Custom combine)				
Total		.738	1.283	.893
Hay (Custom apply P & K)				
Pasture clip[d]	.15	.17	.200	.142
Mow-condition 3 times/yr	.99	1.148	1.20	.849
Rake 3 times/yr	.90	.99	.500	.350
Bale 3 times/yr	.63	.693	.900	.649
Spray insecticide[e]	.098	(.108)	(.067)	(.050)
Contil Total		3.001	2.80	1.99
Mintil Total		3.109	2.867	2.04

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5].

[d]Only clip after oats. Figures are one-half of one treatment and therefore are an average for both meadows in the rotation.

[e]Custom spray with conventional tillage. Cost for application $1.70 per acre. Source: [88].

Table A.3g. Machine operating costs and labor costs for corn and soybeans in C-S-C-O-M-M rotation with minimum tillage on flatland

Operation	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]	Gasoline required gal/acre[c]
Corn (Custom apply P & K)				
Spray contact herbicide[d]	.049	.054	.033	.025
Apply NH_3	.17	.187	.316	.210
Till plant w/ insecticide	.25	.301	.316	.223
Spray pre-emergent herbicide	.098	.108	.067	.050
1st cultivation	.18	.198	.237	.171
2nd cultivation	.18	.198	.237	.171
(Custom combine)				
Total		1.046	1.206	.850
Soybeans (Custom apply P)				
Spray contact herbicide	.098	.108	.067	.050
Till plant	.24	.289	.316	.223
Spray pre-emergent herbicide	.098	.108	.067	.050
1st cultivation	.18	.198	.237	.171
2nd cultivation	.18	.198	.237	.171
(Custom combine)				
Total		.901	.924	.665

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5], assume operations consist of 2/3 diesel power and 1/3 gasoline power.

[d]Apply contact herbicide only for corn following meadow. Figures shown are half the cost of one application and therefore are the average for both corn crops.

Table A.3h. Machine operating costs and labor costs for corn in C-O-M-M-M-M rotation with conventional tillage on flatland

Operation (Custom apply P & K)	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]	Gasoline required gal/acre[c]
Disk stalks	.13	.143	.334	.233
Plow	.40	.44	1.27	.899
Apply NH_3	.17	.187	.316	.210
1st disk	.13	.143	.467	.333
2nd disk w/ herbicide & insecticide	.137[d]	.162[d]	.420	.297
Harrow	.08	.088	.200	.150
Plant	.19	.229	.237	.171
1st cultivation	.18	.198	.237	.171
2nd cultivation	.18	.198	.237	.171
(Custom combine)				
Total		1.788	3.718	2.635

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5].

[d]Field time and labor time adjusted upward by 5% and 13% respectively over first disking for application of chemicals [81, p. 146].

Table A.3i. Machine operating costs and labor costs for oats and hay in C-O-M-M-M-M rotation with conventional tillage on flatland

Operation (Custom apply P & K)	Field time hr/acre[a]	Labor time hr/acre[b]	Diesel required gal/acre[c]	Gasoline required gal/acre[c]
Oats				
1st disk	.13	.143	.334	.233
Apply NH_3	.17	.187	.316	.210
2nd disk	.13	.143	.400	.283
Drill oats w/grass	.22	.265	.233	.167
(Custom combine)				
Total		.738	1.283	.893
Hay				
Pasture clip[d]	.08	.085	.100	.071
Mow-condition 3 times/yr	.99	1.148	1.200	.849
Rake 3 times/yr	.90	.99	.500	.350
Bale 3 times/yr	.63	.693	.900	.649
(Custom spray insecticide)				
Total		2.916	2.700	1.919

[a]Source: [49].

[b]Labor requirements based on labor efficiency factor in [34, p. 20 and pp. 230-232].

[c]Source: [5].

[d]Only clip after oats. Figures are one-fourth of one treatment and therefore are an average for all meadows in the rotation.

Table A.4. Labor and fuel costs for crop rotations

	Contil (Spring Plow)						
	Labor Time	Labor Cost	Diesel Fuel	Diesel Cost	Gasoline	Gasoline Cost	Oil & Filters[a]
C-C-S							
Corn	2.436		6.99				
Corn	2.436		6.99				
Soybeans	1.808		6.121				
Rotation total	6.680	$16.70	20.101	$6.99			$1.05
C-S-C-O-M-M							
Corn	1.744		3.718		2.635		
Soybeans	1.534		3.402		2.425		
Corn	1.733		3.718		2.635		
Oats	.738		1.283		.893		
Meadow	3.001		2.8		1.99		
Meadow	3.001		2.8		1.99		
Rotation total	11.751	$29.37	17.721	$6.17	12.568	$4.39	$1.58
C-O-M-M-M-M							
Corn	1.788		3.718		2.635		
Oats	.738		1.283		.893		
Meadow	2.916		2.700		1.919		
Meadow	2.916		2.700		1.919		
Meadow	2.916		2.700		1.919		
Meadow	2.916		2.700		1.919		
Rotation total	14.19	$35.47	15.801	$5.50	11.204	$3.91	$1.41

[a]15% of fuel cost [6].

Mintil						
Labor Time	Labor Cost	Diesel Fuel	Diesel Cost	Gasoline	Gasoline Cost	Oil & Filter[a]
1.769		3.021	1.05			
1.769		3.021	1.05			
1.249		2.252	.78			
4.787	$11.96	8.294	$2.88			$.43
1.046		1.206		.850		
.901		.924		.665		
1.046		1.206		.850		
.738		1.283		.893		
3.109		2.867		2.04		
3.109		2.867		2.04		
9.499	$24.87	10.353	$3.61	7.338	$2.56	$.92

Table A.5. The total accumulated repair cost equation numbers and the wear out life for farm machinery [20]

Machine	TAR equation number	Wear out life in hours
2-wheel drive tractors	1	12,000
Corn planter	2	1,200
Sprayers	2	2,000
Combine, S.P., base unit and grain heads	3	2,000
Combine cornhead	4	2,000
Moldboard plow	5	2,000
Baler, bale accumulator	7	2,000
Rake	9	2,000
Grain drill	10	1,000
Disk	10	2,000
Cultivator, row-crop or field, rotary hoes	11	2,000
Harrows	11	2,000
Wagons, barge, gravity-flow, flat-rack	11	5,000

Table A.6. *Total accumulated repair cost equations* [20]

1. $TAR = ILP \times 1.2 \times 0.000631 \times L^{1.6}$
2. $TAR = ILP \times 0.8 \times 0.000631 \times L^{1.6}$
3. $TAR = ILP \times 0.33 \times 0.000251 \times L^{1.8}$
4. $TAR = ILP \times 0.50 \times 0.000631 \times L^{1.6}$
5. $TAR = ILP \times 2.00 \times 0.00251 \times L^{1.3}$
6. $TAR = ILP \times 1.80 \times 0.00251 \times L^{1.3}$
7. $TAR = ILP \times 0.85 \times 0.00251 \times L^{1.3}$
8. $TAR = ILP \times 1.20 \times 0.00251 \times L^{1.3}$
9. $TAR = ILP \times 1.00 \times 0.00251 \times L^{1.3}$
10. $TAR = ILP \times 0.65 \times 0.000251 \times L^{1.8}$
11. $TAR = ILP \times 1.00 \times 0.000251 \times L^{1.8}$

Table A.7. Fertilizer applications[a] and costs:[b] conventional tillage

	N	P	K	Cost
	lbs per acre			
C-C-S				
Corn (1)	145	55	30	\$35.70
Corn (2)	175	55	20	38.80
Soybeans	0	50	0	11.00
Rotation Totals	320	160	50	\$85.50
C-S-C-O-M-M				
Corn (1)	35	55	50	\$22.50
Soybeans	0	50	0	11.00
Corn (2)	120	55	30	32.20
Oats	55	45	15	19.25
Meadow (1)	0	45	65	17.05
Meadow (2)	0	45	65	17.05
Rotation Totals	210	295	225	\$119.05
C-O-M-M-M-M				
Corn	35	55	50	\$22.50
Oats	40	45	15	17.15
Meadow (1)	0	45	65	17.05
Meadow (2)	0	45	65	17.05
Meadow (3)	0	45	65	17.05
Meadow (4)	0	45	65	17.05
Rotation Totals	75	280	325	\$107.85

[a]Application rates recommended by Lloyd C. Dumenil, Associate Professor of Agronomy, Iowa State University.

[b]1974 prices (¢/lb): N = 14¢, P = 22¢, K = 11¢. Source: [53, p. 199].

Table A.8. Fertilizer applications[a] and costs:[b] minimum tillage

	N	P	K	Cost
	lbs per acre			
C-C-S				
Corn (1)	165	55	30	$38.50
Corn (2)	195	55	20	41.60
Soybeans	0	50	0	11.00
Rotation Totals	360	160	50	$91.10
C-S-C-O-M-M				
Corn (1)	55	55	50	$25.30
Soybeans	0	50	0	11.00
Corn (2)	140	55	30	35.00
Oats	55	45	15	19.25
Meadow (1)	0	45	65	17.05
Meadow (2)	0	45	65	17.05
Rotation Totals	250	295	275	$124.65

[a]Application rates recommended by Lloyd C. Dumenil, Associate Professor of Agronomy, Iowa State University.

[b]1974 prices (¢/lb): N = 14¢, P = 22¢, K = 11¢. Source: [53, p. 199].

Table A.9. Insecticide[a] and herbicide[b] chemicals

	Insecticide Contil & Mintil			Herbicide Contil		
	Chemical	Rate per acre	Cost	Chemical	Rate per acre	Cost
C-C-S						
Corn (1)	None			Lasso 4E/Atrazine	2 qts/1.5 lb	$9.85
Corn (2)	Thimet 15G	6½ lb	$2.40	Lasso 4E/Atrazine	2 qts/1.5 lb	$9.85
Soybeans	(only emergency appl.)			Lasso 4E/Sencor	2 qts/3/4 lb	$9.90
C-S-C-O-M-M						
Corn (1)	Thimet 15G	6½ lb	$2.40	Lasso 4E/Atrazine	2 qts/1.5 lb	$9.85
Soybeans	(only emergency appl.)			Lasso 4E/Sencor	2 qts/3/4 lb	$9.90
Corn (2)	None			Lasso 4E/Atrazine	2 qts/1.5 lb	$9.85
Oats	None			None		
Meadow (1)	Malathion	1½ pts	$2.25	"		
Meadow (2)	Malathion	1½ pts	$2.25	"		
C-O-M-M-M-M						
Corn	Thimet 15G	6½ lb	$2.40	Lasso 4E/Atrazine	2 qts/1.5 lb	$9.85
Oats	None			None		
Meadow (1)	Malathion		$2.25	"		
Meadow (2)	Malathion		$2.25	"		
Meadow (3)	Malathion		$2.25	"		
Meadow (4)	Malathion		$2.25	"		

[a]Insecticide applications based on [87] and Jerald R. DeWitt, private communication, February 7, 1977.

[b]Herbicide applications based on [54, 24].

Herbicide Mintil		
Chemical	Rate per acre	Cost
Lasse 4E/Atrazine	2½ qts/2 lb	$11.50
Lasso 4E/Atrazine	2½ qts/2 lb	$11.50
Lasso 4E/Sencor/Parquat/X-77	2 qts/1 lb/1 qt/8 oz	$17.28
Lasso 4E/Atrazine/Parquat/X-77	2½ qts/2 lb/2 pts/1 pt	$17.30
Lasso 4E/Sencor/Parquat/X-77	2 qts/1 lb/1 qt/8 oz	$17.28
Lasso 4E/Atrazine	2½ qts/2 lb	$11.50
None		
"		
"		
Lasso 4E/Atrazine/Parquat/X-77	2½ qts/2 lb/2 pts/1 pt	$17.30
None		
"		
"		
"		
"		

Table A.10. Seed, chemical, hauling, drying, storage, and custom costs for crop rotations

	Contil							
	Fertilizer	Seed	Insecti-cide	Herbi-cide	Drying[a]	Stor-age[a]	Haul-ing[b]	Custom costs[c]
C-C-S								
Corn (1)	35.70	6.85	-	9.85	10.50	3.50	2.11	1.04
Corn (2)	38.80	6.85	2.40	9.85	10.50	3.50	2.11	1.04
Soybeans	11.00	9.90	-	9.90	-	1.22	.80	1.04
Rotation Totals	$85.50	$23.60	$2.40	$29.60	$21.00	$8.22	$5.02	$3.12
C-S-C-O-M-M								
Corn (1)	22.50	6.85	2.40	9.85	10.50	3.50	2.11	9.56[d]
Soybeans	11.00	9.90	-	9.90	-	1.22	.80	7.62[d]
Corn (2)	32.20	6.85	-	9.85	10.50	3.50	2.11	9.56[d]
Oats	19.25	8.38	-	-	-	1.92	1.11	7.11[d]
Meadow (1)	17.05	20.50	2.25	-	-	1.19	9.84	2.59[e]
Meadow (2)	17.05	-	2.25	-	-	1.19	9.84	2.59[e]
Rotation Totals	$119.05	$52.48	$6.90	$29.60	$21.00	$12.52	$25.81	$39.03
C-O-M-M-M-M								
Corn	22.50	6.85	2.40	9.85	10.50	3.50	2.11	9.56[d]
Oats	17.15	8.38	-	-	-	1.92	1.11	7.11[d]
Meadow	17.05	20.50	2.25	-	-	1.19	9.84	2.59[e]
Meadow	17.05	-	2.25	-	-	1.19	9.84	2.59[e]
Meadow	17.05	-	2.25	-	-	1.19	9.84	2.59[e]
Meadow	17.05	-	2.25	-	-	1.19	9.84	2.59[e]
Rotation Totals	$107.85	$35.73	$11.40	$9.85	$10.50	$10.18	$42.58	$27.03

[a]Source: [88].

[b]Variable costs only; labor, fuel and repairs. Source: [88].

[c]Custom application of P and K fertilizer only unless otherwise indicated. Source [88].

[d]Includes custom combine.

[e]Includes custom spraying of insecticide.

Mintil		
Fertilizer	Herbicides	Custom costs
38.50	11.50	1.04
41.60	11.50	1.04
11.00	17.28	1.04
$91.10	$40.28	$3.12
25.30	17.30	9.56[d]
11.00	17.28	7.62[d]
35.00	11.50	9.56[d]
19.25	-	7.11[d]
17.05	-	1.04
17.05	-	1.04
$124.65	$46.08	$35.93

Table A.11a. C-C-S costs - spring-plow

	S1 on A and A1 land		S1 on B land		S1 on C land		S1 on D land	
Repairs	17.42		17.42		17.42		17.42	
Labor	16.70		17.03		17.37		17.70	
Seed	23.60		23.60		23.60		23.60	
Pesticide	32.00		32.00		32.00		32.00	
Custom costs	3.12		3.12		3.12		3.12	
Hauling	5.02		5.02		5.02		5.02	
Storage	8.22		8.22		8.22		8.22	
Drying	21.00		21.00		21.00		21.00	
Fertilizer	85.50		85.50		85.50		85.50	
Oil & filters	1.05		1.05		1.05		1.05	
Fuel	6.99		6.99		6.99		6.99	
Sub Total		220.62		220.95		221.29		221.62
Equipment cost	125.63		125.63		125.63		125.63	
Terrace cost[a]	-		-		-		-	
Sub Total		125.63		125.63		125.63		125.63
Rotation Total		$346.25		$346.58		$346.92		$347.25

[a]From Table A.12.

S1 on E land	SC1	ST1 on B land	ST2 on C land	ST1 on D land	ST1 on E land
17.42	17.42	16.93	16.03	15.35	13.69
18.04	17.87	16.23	15.36	14.71	13.13
23.60	23.60	22.94	21.71	20.79	18.55
32.00	32.00	31.10	29.44	28.19	25.15
3.12	3.12	3.03	2.87	2.75	2.45
5.02	5.02	4.88	4.62	4.42	3.95
8.22	8.22	7.99	7.56	7.24	6.46
21.00	21.00	20.41	19.32	18.50	16.51
85.50	85.50	83.11	78.66	75.33	67.20
1.05	1.10	1.03	.97	.93	.82
6.99	7.34	6.79	6.43	6.16	5.49
221.96	222.19	214.44	202.97	194.37	173.40
125.63	125.63	125.63	125.63	125.63	125.63
-	-	31.89	57.42	54.81	70.20
125.63	125.63	157.52	183.05	180.44	195.83
$347.59	$347.82	$371.96	$386.02	$374.81	$369.23

Table A.11b. C-S-C-O-M-M costs - spring-plow

	S2 on A and A1 land		S2 on B land		S2 on C land		S2 on D land	
Repairs	22.34		22.34		22.34		22.34	
Labor	29.37		29.96		30.54		31.13	
Seed	52.48		52.48		52.48		52.48	
Pesticide	36.50		36.50		36.50		36.50	
Custom costs	39.03		39.03		39.03		39.03	
Hauling	25.81		25.81		25.81		25.81	
Storage	12.52		12.52		12.52		12.52	
Drying	21.00		21.00		21.00		21.00	
Fertilizer	119.05		119.05		119.05		119.05	
Oil & filters	1.58		1.58		1.58		1.58	
Fuel	10.56		10.56		10.56		10.56	
Sub Total		370.24		370.83		371.41		372.00
Equipment cost	156.12		156.12		156.12		156.12	
Terrace cost[a]	-		-		-		-	
Sub Total		156.12		156.12		156.12		156.12
Rotation Total		$526.36		$526.95		$527.53		$528.12

[a] From Table A.12.

S2 on E land	SC2	ST1 on B land	ST2 on C land	ST2 on D land	ST2 on E land
22.34	22.34	21.71	20.55	19.68	17.56
31.72	31.42	28.55	27.02	25.87	23.08
52.48	52.48	51.10	48.28	46.23	41.25
36.50	36.50	35.48	33.58	32.16	28.69
39.03	39.03	37.94	35.91	34.39	30.68
25.81	25.81	25.09	23.74	22.74	20.29
12.52	12.52	12.17	11.52	11.04	9.84
21.00	21.00	20.41	19.32	18.50	16.51
119.05	119.05	115.72	109.53	104.88	93.56
1.58	1.66	1.53	1.45	1.39	1.24
10.56	11.09	10.26	9.72	9.30	8.30
372.59	372.90	359.87	340.62	326.18	291.01
156.12	156.12	156.12	156.12	156.12	156.12
-	-	63.78	114.84	109.62	140.40
156.12	156.12	219.90	270.96	265.74	296.52
$528.71	$529.02	$579.77	$611.58	$591.92	$587.53

Table A.11c. C-O-M-M-M-M costs - spring-plow and fall-plow

	S3 on A and A1 land	S3 on B land	S3 on C land	S3 on D land
Repairs	27.47	27.47	27.47	27.47
Labor	35.47	36.18	36.89	37.60
Seed	35.73	35.73	35.73	35.73
Pesticide	21.25	21.25	21.25	21.25
Custom cost	27.03	27.03	27.03	27.03
Hauling	42.58	42.58	42.58	42.58
Storage	10.18	10.18	10.18	10.18
Drying	10.50	10.50	10.50	10.50
Fertilizer	107.85	107.85	107.85	107.85
Oil & filters	1.41	1.41	1.41	1.41
Fuel	9.41	9.41	9.41	9.41
Sub Total	328.88	329.59	330.30	331.01
Equipment cost	142.91	142.91	142.91	142.91
Terrace cost[a]	-	-	-	-
Sub Total	142.91	142.91	142.91	142.91
Rotation Total	$471.79	$472.50	$473.21	$473.92

[a] From Table A.12.

S3 on E land	SC3	ST3 on B land	ST3 on C land	ST3 on D land	ST3 on E land
27.47	27.47	26.70	25.27	24.20	21.59
38.31	37.95	34.48	32.63	31.25	27.88
35.73	35.73	34.73	32.87	31.48	28.08
21.25	21.25	20.65	19.55	18.72	16.70
27.03	27.03	26.27	24.87	23.81	21.24
42.58	42.58	41.39	39.17	37.51	33.48
10.18	10.18	9.89	9.36	8.97	8.00
10.50	10.50	10.21	9.67	9.25	8.25
107.85	107.85	104.83	99.22	95.02	84.77
1.41	1.48	1.37	1.30	1.24	1.11
9.41	9.88	9.15	8.66	8.29	7.40
331.72	331.90	319.67	302.57	289.74	258.50
142.91	142.91	142.91	142.91	142.91	142.91
-	-	63.78	114.84	109.62	140.40
142.91	142.91	206.69	257.75	252.53	283.31
$474.63	$474.81	$526.36	$560.32	$542.27	$541.81

Table A.11d. C-C-S costs - minimum tillage

	M1 on A and A1 land		M1 on B land		M1 on C land		M1 on D land	
Repairs	11.76		11.76		11.76		11.76	
Labor	11.96		12.20		12.44		12.68	
Seed	23.60		23.60		23.60		23.60	
Pesticide	42.68		42.68		42.68		42.68	
Custom cost	3.12		3.12		3.12		3.12	
Hauling	5.02		5.02		5.02		5.02	
Storage	8.22		8.22		8.22		8.22	
Drying	21.00		21.00		21.00		21.00	
Fertilizer	91.10		91.10		91.10		91.10	
Oil & filters	.43		.43		.43		.43	
Fuel	2.88		2.88		2.88		2.88	
Sub Total		221.77		222.01		225.25		222.49
Equipment cost	88.68		88.68		88.68		88.68	
Terrace cost[a]	-		-		-		-	
Sub Total		88.68		88.68		88.68		88.68
Rotation Total		$310.45		$310.69		$310.93		$311.17

[a]From Table A.12.

M1 on E land		MC1		MT1 on C land		MT1 on D land		MT1 on E land	
11.76		11.76		10.96		10.36		9.24	
12.92		12.80		11.15		10.54		9.40	
23.60		23.60		22.00		20.79		18.55	
42.68		42.68		39.78		37.60		33.55	
3.12		3.12		2.91		2.75		2.45	
5.02		5.02		4.68		4.42		3.95	
8.22		8.22		7.66		7.24		6.46	
21.00		21.00		19.57		18.50		16.51	
91.10		91.10		84.90		80.26		71.60	
.43		.45		.40		.38		.34	
2.88		3.02		2.68		2.54		2.26	
	222.73		222.77		206.69		195.38		174.31
88.68		88.68		88.68		88.68		88.68	
-		-		48.81		54.81		70.20	
	88.68		88.68		137.49		143.49		158.88
	$311.41		$311.45		$344.18		$338.87		$333.19

Table A.11e. C-S-C-O-M-M costs - minimum tillage

	M2 or A and A1 land		M2 on B land		M2 on C land		M2 on D land	
Repairs	19.94		19.94		19.94		19.94	
Labor	24.87		25.37		25.86		26.36	
Seed	52.48		52.48		52.48		52.48	
Pesticide	52.98		52.98		52.98		52.98	
Custom cost	35.93		35.93		35.93		35.93	
Hauling	25.81		25.81		25.81		25.81	
Storage	12.52		12.52		12.52		12.52	
Drying	21.00		21.00		21.00		21.00	
Fertilizer	124.65		124.65		124.65		124.65	
Oil & filters	.92		.92		.92		.92	
Fuel	6.17		6.17		6.17		6.17	
Sub Total		377.27		377.77		378.26		378.76
Equipment cost	153.01		153.01		153.01		153.01	
Terrace cost[a]	-		-		-		-	
Sub Total		153.01		153.01		153.01		153.01
Rotation Total		$530.28		$530.78		$531.27		$531.77

[a]From Table A.12.

M2 on E land	MC2	MT2 on C land	MT2 on D land	MT2 on E land
19.94	19.94	18.58	17.57	15.67
26.86	26.60	23.18	21.91	19.55
52.48	52.48	48.92	46.23	41.25
52.98	52.98	49.38	46.67	41.64
35.93	35.93	33.49	31.65	28.24
25.81	25.81	24.05	22.74	20.29
12.52	12.52	11.67	11.03	9.84
21.00	21.00	19.57	18.50	16.51
124.65	124.65	116.17	109.82	97.97
.92	.97	.86	.81	.72
6.17	6.49	5.75	5.44	4.85
379.26	379.37	351.62	332.37	296.53
153.01	153.01	153.01	153.01	153.01
-	-	97.62	109.62	140.40
153.01	153.01	250.63	262.63	293.41
$532.27	$532.38	$602.25	$595.00	$589.94

Table A.11f. C-C-S costs - fall-plow

	C1 on A and A1 land		C1 on B land		C1 on C land		C1 on D land	
Repairs	18.50		18.50		18.50		18.50	
Labor	18.01		18.37		18.73		19.09	
Seed	23.60		23.60		23.60		23.60	
Pesticide	32.00		32.00		32.00		32.00	
Custom costs	3.12		3.12		3.12		3.12	
Hauling	5.02		5.02		5.02		5.02	
Storage	8.22		8.22		8.22		8.22	
Drying	21.00		21.00		21.00		21.00	
Fertilizer	85.50		85.50		85.50		85.50	
Oil & filters	1.13		1.13		1.13		1.13	
Fuel	7.51		7.51		7.51		7.51	
Sub Total		223.61		223.47		224.33		224.69
Equipment cost	95.67		95.67		95.67		95.67	
Terrace cost[a]	-		-		-		-	
Sub Total		95.67		95.67		95.67		95.67
Rotation Total		$319.28		$319.64		$320.00		$320.36

[a]From Table A.12.

C1 on E land	CC1	CT1 on B land	CT1 on C land	CT1 on D land	CT1 on E land
18.50	18.50	17.98	17.02	16.30	14.54
19.45	19.27	17.51	16.57	15.87	14.16
23.60	23.60	22.94	21.71	20.79	18.55
32.00	32.00	31.10	29.44	28.19	25.15
3.12	3.12	3.03	2.87	2.75	2.45
5.02	5.02	4.88	4.62	4.42	3.94
8.22	8.22	7.99	7.56	7.24	6.46
21.00	21.00	20.41	19.32	18.50	16.51
85.50	85.50	83.11	78.66	75.32	67.21
1.13	1.19	1.10	1.04	1.00	.89
7.51	7.88	7.30	6.91	6.62	5.90
225.05	225.30	217.35	205.72	197.00	175.76
95.67	95.67	95.67	95.67	95.67	95.67
-	-	31.89	57.42	54.81	70.20
95.67	95.67	127.56	153.09	150.48	165.87
$320.72	$320.97	$344.91	$358.81	$347.48	$341.63

Table A.11g. C-S-C-O-M-M costs - fall-plow

	C2 on A and A1 land		C2 on B land		C2 on C land		C2 on D land	
Repairs	23.14		23.14		23.14		23.14	
Labor	30.79		31.40		32.02		32.64	
Seed	52.48		52.48		52.48		52.48	
Pesticide	36.50		36.50		36.50		36.50	
Custom cost	39.03		39.03		39.03		39.03	
Hauling	25.81		25.81		25.81		25.81	
Storage	12.52		12.52		12.52		12.52	
Drying	21.00		21.00		21.00		21.00	
Fertilizer	119.05		119.05		119.05		119.05	
Oil & filters	1.67	1.67	1.67	1.67				
Fuel	11.13		11.13		11.13		11.13	
Sub Total		373.12		373.73		374.35		374.97
Equipment cost	128.84		128.84		128.84		128.84	
Terrace cost[a]	-		-		-		-	
Sub Total		128.84		128.84		128.84		128.84
Rotation Total		$501.96		$502.57		$503.19		$503.81

[a]From Table A.12.

C2 on E land	CC2	CT2 on B land	CT2 on C land	CT2 on D land	CT2 on D land
23.14	23.14	22.49	21.29	20.39	18.19
33.25	32.94	29.93	28.33	27.13	24.20
52.48	52.48	51.01	48.27	46.23	41.25
36.50	36.50	35.48	33.58	32.16	28.69
39.03	39.03	37.94	35.91	34.38	30.67
25.81	25.81	25.09	23.74	22.74	20.29
12.52	12.52	12.17	11.52	11.03	9.84
21.00	21.00	20.41	19.32	18.50	16.51
119.05	119.05	115.71	109.53	104.88	93.57
1.67	1.75	1.62	1.54	1.47	1.31
11.13	11.69	10.82	10.24	9.80	8.75
375.58	375.91	362.67	343.27	328.71	293.27
128.84	128.84	128.84	128.84	128.84	128.84
-	-	63.78	114.84	109.62	140.40
128.84	128.84	192.62	243.68	238.46	269.24
$504.42	$504.75	$555.29	$586.95	$567.17	$562.51

Table A.12. Terrace dimensions and costs

Land Class	Interval[a] ft	Back-slope ft	Terrace spacing ft[b]	% of land in grass Backslope	Effective slope length[c]	Terrace linear footage per acre[d]	Const. cost per foot[e]	Const. cost per acre	Annual capitalized const. cost per acre[f]	Annual maint. cost[e]	Total cost per acre
					Conventional Tillage in Row Crops						
B	240	7	247	2.8	225	176.35	.48	$85	$8.65	$1.98	$10.63
C	126	11	137	8.0	111	317.96	.48	$153	$15.58	$3.56	$19.14
D	126	17	143	11.9	111	304.62	.48	$146	$14.86	$3.41	$18.27
E	88	24	112	21.4	73	388.93	.48	$187	$19.04	$4.36	$23.40
					Minimum Tillage in Row Crops						
C	150	11	161	6.8	135	270.56	.48	$130	$13.24	$3.03	$16.27
D	126	17	143	11.9	111	304.62	.48	$146	$14.86	$3.41	$18.27
E	88	24	112	21.4	73	388.93	.48	$187	$19.04	$4.36	$23.40

[a]Toe of backslope to top of ridge on next lower terrace - cultivated interval. Source: [101]. Interval adjusted to fit 38" row equipment.

[b]Distance between terrace ridges.

[c]Distance between toe of backslope and mid-channel of terrace below. Based on 15 foot length of frontslope.

[d]Linear feet of terrace per acre = $\frac{\text{43,560 sq. ft. per acre}}{\text{Terrace spacing}}$.

[e]Source: Lewis Grissom, District Conservationist located in Mills County. Private communication, April 13, 1977.

[f]Capital recovery factor = $\frac{r(1+r)^n}{(1+r)^n - 1}$ = .10181 for r = .09, n = 25 years.

Table A.13. Hay production costs

	Fixed cost per acre[a]	Variable cost per acre[a]	Labor time per acre[b]	Labor cost per acre	
I. Establishment Costs for Meadow and Nursecrop Oats (incurred in 1 year)					
A. Equipment & Labor					
Custom bulk fert.	-	$1.04[c]	-		
Disk	$1.20	.96	.29		
Harrow	.37	.24	.09		
Drill seed	.66	.42	.27		
Clip stubble	.96	.68	.34	$2.50	
Wagons, etc.	.98	.36	-	x.99	
Subtotal	$4.17	$3.70	.99 hrs	$2.48	
B. Seed & Chemicals					
Seed[d]		$28.50			
Fertilizer[e]		17.15			
		$45.65			
C. Harvesting Oats					
Combine	$5.30	$2.03	.35		
Haul grain	.70	.61	.20	$2.50	
Storage	2.62	-	-	x.55	
Subtotal	$8.62	$2.64	.55 hrs	$1.38	
Total	$12.79	$51.99		$3.86	Type I cost per acre in 1 year $68.64

[a]Source: [88].

[b]Source: [49]. Adjusted with labor efficiency factor from [34].

[c]Source: [88].

[d]Oats, alfalfa and brome.

[e]Fertilizer application 40-45-15 on oats.

Table A.13 (Continued)

	Fixed cost per acre[a]	Variable cost per acre[a]	Labor time per acre[b]	Labor cost per acre	
II. Maintenance and Harvesting Costs for Hay (incurred in each of 5 years)					
A. Equipment & Labor					
Custom bulk fertilizer	-	$1.04	-		
Mow and condition	$5.17	2.31	1.15		
Rake	2.24	1.41	.99		
Bale	7.85	11.25	.69		
Haul & unload bales	2.30	1.72	3.25		
Storage	1.55	-	-	$2.50	
Wagons & misc. machinery	.90	.60	.35	6.43	
Subtotal	$20.01	$18.33	6.43 hr	$16.08	
B. Fertilizer[e]		$17.05			
Total	$20.01	35.38		$16.08	Type II cost per acre in 1 year $71.47
					Total cost per 6 acre rotation $425.99

APPENDIX B

Table B.1. Soil loss per acre[a]

Land Class	Crop Activity[b]	R	K	LS	P[c]	RKLSP	Fall-Plow C	Fall-Plow Soil Loss	Spring-Plow C	Spring-Plow Soil Loss	Minimum Tillage C	Minimum Tillage Soil Loss
Slope A	C1	167	.32	.215	1	11.490	.41[d]	4.71	.36[e]	4.14		
	C2	167	.32	.215	1	11.490	.18[d]	2.07	.16[e]	1.84		
	C3	167	.32	.215	1	11.490	.036	.41	.032	.37		
	CC1	167	.32	.215	.6	6.894	.41[d]	2.83	.36[e]	2.48		
	CC2	167	.32	.215	.6	6.894	.18[d]	1.24	.16[e]	1.10		
	CC3	167	.32	.215	.6	6.894	.036	.25	.032	.22		
	M1	167	.32	.215	1	11.490					.20[f]	2.30
	M2	167	.32	.215	1	11.490					.11[f]	1.26
	MC1	167	.32	.215	.41	4.711					.20[f]	.94
	MC2	167	.32	.215	.41	4.711					.11[f]	.52
	H	167	.32	.215	1	11.490	.01[g]	.11				

[a]Except where indicated otherwise, source of soil loss factors is [116].

[b]For crop activity legend see Figure 4.1.

[c]Source: [11].

[d]From Table B.2.

[e]From Table B.3.

[f]From Table B.4.

[g]From Table B.5.

Table B.1 (Continued)

Land Class	Crop Activity[b]	R	K	LS	P[c]	RKLSP	Fall-Plow C	Fall-Plow Soil Loss	Spring-Plow C	Spring-Plow Soil Loss	Minimum Tillage C	Minimum Tillage Soil Loss
Slope B	C1	167	.32	.546	1	29.178	.41	11.96	.36	10.50		
	C2	167	.32	.546	1	29.178	.18[d]	5.25	.16[e]	4.67		
	C3	167	.32	.546	1	29.178	.036	1.05	.032	.93		
	CC1	167	.32	.546	.5	14.589	.41	5.98	.36	5.25		
	CC2	167	.32	.546	.5	14.589	.18[d]	2.63	.16[e]	2.33		
	CC3	167	.32	.546	.5	14.589	.036	.52	.032	.47		
	CT1	167	.32	.455	.10	2.432	.41	1.00	.36	.88		
	CT2	167	.32	.455	.10	2.432	.18[d]	.44	.16[e]	.39		
	CT3	167	.32	.455	.10	2.432	.036	.09	.032	.08		
	M1	167	.32	.546	1	29.178					.20	5.84
	M2	167	.32	.546	1	29.178					.11[f]	3.21
	MC1	167	.32	.546	.30	8.753					.20	1.75
	MC2	167	.32	.546	.30	8.753					.11[f]	.96
	H	167	.32	.546	1	29.178						
Slope C	C1	167	.32	1.426	1	76.205	.41	31.24	.36	27.43		
	C2	167	.32	1.426	1	76.205	.18[d]	13.72	.16[e]	12.19		
	C3	167	.32	1.426	1	76.205	.036	2.74	.032	2.44		
	CT1	167	.32	.863	.11	5.073	.41	2.08	.36	1.83		
	CT2	167	.32	.863	.11	5.073	.18[d]	.91	.16[e]	.81		
	CT3	167	.32	.863	.11	5.073	.036	.18	.032	.16		
	M1	167	.32	1.426	1	76.205					.20	15.24
	M2	167	.32	1.426	1	76.205					.11[f]	8.38
	MC1	167	.32	1.426	.35	26.672					.20	5.33
	MC2	167	.32	1.426	.35	26.672					.11[f]	2.93
	MT1	167	.32	.952	.11	5.596					.20	1.12
	MT2	167	.32	.952	.11	5.596					.11[f]	.62
	H	167	.32	1.426	1	76.205	.01[g]	.76				

Table B.1 (Continued)

Land Class	Crop Activity[b]	R	K	LS	P[c]	RKLSP	Fall-Plow C	Fall-Plow Soil Loss	Spring-Plow C	Spring-Plow Soil Loss	Minimum Tillage C	Minimum Tillage Soil Loss
Slope D	C1	167	.32	2.898	1	154.869	.41	63.50	.36	55.75		
	C2	167	.32	2.898	1	154.869	.18[d]	27.88	.16[e]	24.78		
	C3	167	.32	2.898	1	154.869	.036	5.58	.032	4.96		
	CT1	167	.32	1.663	.13	11.553	.41	4.74	.36	4.16		
	CT2	167	.32	1.663	.13	11.553	.18[d]	2.08	.16[e]	1.85		
	CT3	167	.32	1.663	.13	11.553	.036	.42	.032	.37		
	M1	167	.32	2.898	1	154.869					.20	30.97
	M2	167	.32	2.898	1	154.869					.11[f]	17.04
	MT1	167	.32	1.663	.13	11.553					.20	2.31
	MT2	167	.32	1.663	.13	11.553					.11[f]	1.27
	H	167	.32	2.898	1	154.869	.01[g]	1.54				
Slope E	C	167	.32	5.638	1	301.295	.41	123.53	.36	123.53		
	C2	167	.32	5.638	1	301.295	.18[d]	54.23	.18[d]	54.23		
	C3	167	.32	5.638	1	301.295	.036	10.85	.036	10.85		
	CT1	167	.32	2.452	.16	20.966	.41	8.60	.41	8.60		
	CT2	167	.32	2.452	.16	20.966	.18[d]	3.77	.16[e]	3.35		
	CT3	167	.32	2.452	.16	20.966	.036	.75	.032	.67		
	M1	167	.32	5.638	1	301.295					.20	60.26
	M2	167	.32	5.638	1	301.295					.11[f]	33.14
	MT1	167	.32	2.452	.16	20.966					.20	4.19
	MT2	167	.32	2.452	.16	20.966					.11[f]	2.31
	H	167	.32	5.638	1	301.295			.01[g]	3.01		

Table B.1 (Continued

Land Class	Crop Activity[b]	R	K	LS	P	RKLSP	Spring-Plow	
							C	Soil Loss
F	PP	167	.32	9.828	1	525.208	.006	3.15
G	PP	167	.32	17.328	1	926.008	.006	5.56
AP	PP	167	.32	.215	1	11.490	.004	.05
BP	PP	167	.32	.546	1	29.178	.004	.12
CP	PP	167	.32	1.426	1	76.205	.004	.30
DP	PP	167	.32	2.898	1	154.869	.004	.62
EP	PP	167	.32	5.638	1	301.295	.004	1.20

Table B.2. C-factor derivation for C-S-C-O-M-M conventional tillage fall plow with crop residue left

Operation	Date Started	Cumulative EI: Curve 13	Crop Stage Ending	% E.I. Period	Soil Loss Ratio (%)[a]	Columns 5x6	Crop Subtotal
Corn after meadow							
Plow	11/1	98	Meadow	-	-	-	
Plant corn	5/1	107	Fallow	9	15[b]	.0135	
	6/1	119	C1	12	32	.0384	
	7/1	147	C2	28	17	.0476	
Harvest corn	10/10	195	C3	48	10	.048	
	11/1	198	C4	3	15	.0045	.1520
Soybeans after corn							
Plow	11/1	198	C4	-	-		
Plant beans	5/10	210	Fallow	12	39[c]	.0468	
	6/10	228	S1	18	56	.1008	
	7/10	254	S2	26	40	.1040	
Harvest beans	9/25	292	S3	38	22	.0836	
	11/1	298	S4	6	25	.015	.3502
Corn after beans							
Plow	11/1	298	S4	-	-		
Plant corn	5/1	307	Fallow	9	50[d]	.045	
	6/1	319	C1	12	82	.0996	
	7/1	347	C2	28	60	.1680	
Harvest corn	10/10	395	C3	48	31	.1488	
	4/1	402	C4	7	36	.0252	.4866

[a]All table references are found in [116].

[b]Line 1 of Table 2 and Table 3 for fall-plowing note.

[c]Line 15 of Table 2 multiplied by (.9) as suggested by Table 3, further adjusted according to note on fall plowing in Table 3.

[d]Line 36 of Table 2 adjusted up by 20% due to findings in [61] and adjusted according to note on fall plowing in Table 3.

Table B.2 (Continued)

Operation	Date Started	Cumulative EI: Curve 13	Crop Stage Ending	% E.I. Period	Soil Loss Ratio (%)[a]	Columns 5x6	Crop Subtotal
Oats after corn							
Disk	4/1	402	C4	-	-		
Seed oats	4/10	404	Fallow	2	36[e]	.0072	
	5/10	410	01	6	32[f]	.0192	
	6/10	428	02	18	19	.0342	
Harvest oats	7/10	454	03	26	5	.0130	
	9/10	486	04	32	3	.0096	.0832
Meadow (2 crops)	9/10	486	04	-	-		
	9/10	586	Meadow	100	.4[g]	.004	
	9/10	686	Meadow	100	.4	.004	
Plow	11/1	698	Meadow	12	.4	.00048	.0085
				Rotation Total 6 acres			1.0805

Average soil loss per acre .1801, C-factor = .18

[e]Soil loss ratio for disked stalks is taken to be the same as for corn in crop stage 4.

[f]Line 93 of Table 2.

[g]Line 120 of Table 2.

Table B.3. C-factor derivation for C-S-C-O-M-M conventional tillage spring-plow with crop residue left

Operation	Date Started	Cumulative EI: Curve 13	Crop Stage Ending	% E.I. Period	Soil Loss Ratio (%)[a]	Columns 5x6	Crop Subtotal
Corn after meadow							
Plow	4/15	4	Meadow	-	-		
Plant corn	5/1	7	Fallow	3	8[b]	.0024	
	6/1	19	C1	12	25	.0300	
	7/1	47	C2	28	17	.0476	
Harvest corn	10/10	95	C3	48	10	.048	
	4/25	106	C4	11	15	.0165	.1445
Soybeans after corn							
Plow	4/25	106	C4	-	-		
Plant beans	5/10	110	Fallow	4	32[c]	.0128	
	6/10	128	S1	18	49	.0882	
	7/10	154	S2	26	40	.1040	
Harvest beans	9/25	192	S3	38	22	.0836	
	4/15	204	S4	12	25	.0300	.3186
Corn after beans							
Plow	4/15	204	S4	-	-		
Plant corn	5/1	207	Fallow	3	43[d]	.0129	
	6/1	219	C1	12	76	.0912	
	7/1	247	C2	28	60	.1680	
Harvest corn	10/10	295	C3	48	31	.1488	
	4/1	302	C4	7	36	.0252	.4461

[a] All table references are found in [116].

[b] Line 1 of Table 2.

[c] Line 15 of Table 2 multiplied by (.9) as suggested by Table 3.

[d] Line 36 of Table 2 adjusted up by 20% due to findings in source [46].

Table B.3 (Continued)

Operation	Date Started	Cumulative EI: Curve 13	Crop Stage Ending	% E.I. Period	Soil Loss Ratio (%)[a]	Columns 5x6	Crop Subtotal
Oats after corn							
Disk	4/1	302	C4	-	-		
Seed oats	4/10	304	Fallow	2	36[e]	.0072	
	5/10	310	O1	6	32[f]	.0192	
	6/10	328	O2	18	19	.0342	
Harvest oats	7/10	354	O3	26	5	.0130	
	9/10	386	O4	32	3	.0096	.0832
Meadow (2 crops)	9/10	386	O4	-	-		
	9/10	486	Meadow	100	.4[g]	.004	
	9/10	586	Meadow	100	.4	.004	
Plow	4/15	604	Meadow	18	.4	.0072	.0087
			Rotation total for 6 acres				1.0404
			Average soil loss per acre				.1654
			C-factor = .16				

[e]Soil loss ratio for disked stalks is taken to be the same as for corn in crop stage 4.

[f]Line 93 of Table 2.

[g]Line 120 of Table 2.

Table B.4. C-factor derivation for C-S-C-O-M-M minimum tillage

Operation	Date Started	Cumulative EI: Curve 13	Crop Stage Ending	% E.I. Period	Soil Loss Ratio (%) [a]	Columns 5x6	Crop Subtotal
Corn after meadow							
Plant corn	5/1	7	Meadow	-	-		
	6/1	19	C1	12	8 [b]	.0096	
	7/1	47	C2	28	8	.0224	
Harvest corn	10/10	95	C3	48	6	.0288	
	5/10	110	C4	15	15	.0225	.0833
Soybeans after corn							
Plant beans	5/10	110	C4	-	-		
	6/10	128	S1	18	31.5 [c]	.0567	
	7/10	154	S2	26	31.5	.0819	
Harvest beans	9/25	192	S3	38	12.6	.04788	
	5/1	207	S4	15	25.2	.0378	.2243
Corn after beans							
Plant corn	5/1	207	S4	-	-		
	6/1	219	C1	12	43 [d]	.0516	
	7/1	247	C2	28	43	.1204	
Harvest corn	10/10	295	C3	48	19	.0912	
	4/1	302	C4	7	36	.0252	.2884

[a] All table references are found in [116].

[b] Line 8 of Table 2.

[c] Line 21 of Table 2 multiplied by (.9) as suggested by Table 3.

[d] Line 40 adjusted up by 20% due to findings in [61].

Table B.4 (Continued)

Operation	Date Started	Cumulative EI: Curve 13	Crop Stage Ending	% E.I. Period	Soil Loss Ratio (%)[a]	Columns 5x6	Crop Subtotal
Oats after corn							
Disk	4/1	302	C4	-	-		
	4/10	304	Fallow	2	36[e]	.0072	
	5/10	310	01	6	32[f]	.0192	
	6/10	328	02	18	19	.0342	
Harvest oats	7/10	354	03	26	5	.0130	
	9/10	386	04	32	3	.0096	.0832
Meadow							
(2 crops)	9/10	386	04	-	-		
	9/10	486	Meadow	100	.4[g]	.004	
	9/10	586	Meadow	100	.4	.004	
Plant corn	5/1	607	Meadow	21	.4	.00084	.00884

Rotation total for 6 acres .68804

Average soil loss per acre .1147

C-factor = .11

[e] Soil loss for disked stalks is taken to be the same as for corn in crop stage 4.

[f] Line 93 of Table 2.

[g] Line 120 of Table 2.

Table B.5. C-factor derivation for meadow with oats nursecrop

Operation	Date Started	Cumulative EI: Curve 13	Crop Stage Ending	% E.I. Period	Soil Loss Ratio (%)[a]	Columns 5x6	Crop Subtotal
Oats							
Disk	4/1	02	Meadow	-	-[b]		
Seed oats	4/10	04	Fallow	2	1[e]	.0002	
	5/10	10	01	6	20	.012	
	6/10	28	02	18	12	.0216	
Harvest oats	7/10	54	03	26	2	.0056	
	9/10	86	04	32	2	.007	.0464
Meadow							
(5 crops)	9/10	86	04	-	-		
	9/10	186	Meadow	100	.4[g]	.004	
	9/10	286	Meadow	100	.4	.004	
	9/10	386	Meadow	100	.4	.004	
	9/10	486	Meadow	100	.4	.004	
	9/10	586	Meadow	100	.4	.004	
Disk	4/1	602	Meadow	16	.4	.00064	.02064

Rotation total 6 acres .06704

Average soil loss per acre .0111

C-factor = .01

Table B.6. Soil loss and sediment concentration - fall-plow

	Rotation Soil Loss[a]	Include Gully Erosion[b]	Sediment Conversion[c]	Sediment Load DR=.20	DR=.25	DR=.30
	tons/acre			10^{-3} mg/liter		
Slope A						
C1	14.13	17.6625	16.3130	3.2626	4.0782	4.8939
C2	12.42	15.525	14.3387	2.8677	3.5847	4.3016
C3	2.46	3.075	2.8400	.5680	.7100	.8520
CC1	8.49	10.6125	9.8016	1.9603	2.4504	2.9405
CC2	7.44	9.3	8.5894	1.7179	2.1473	2.5768
CC3	1.5	1.875	1.7317	.3463	.4329	.5195
Slope B						
C1	35.88	44.85	41.4230	8.2846	10.3558	12.4269
C2	31.5	39.375	36.3664	7.2733	9.0916	10.9100
C3	6.3	7.875	7.2733	1.4547	1.8183	2.1820
CC1	17.94	22.425	20.7115	4.1423	5.1779	6.2135
CC2	15.78	19.725	18.2178	3.6436	4.5545	5.4653
CC3	3.12	3.9	3.6032	.7206	.9008	1.0810
CT1	3.00	3.00	2.7708	.5542	.6927	.8312
CT2	2.64	2.64	2.4382	.4877	.6096	.7315
CT3	.54	.54	.4987	.0997	.1247	.1496
Slope C						
C1	93.72	117.15	108.1986	21.6397	27.0496	32.4596
C2	82.32	102.9	95.0374	19.0075	23.7594	28.5112
C3	16.44	20.55	18.9798	3.7960	4.7449	5.6939
CT1	6.24	6.24	5.7632	1.1526	1.4408	1.7290
CT2	5.46	5.46	5.0428	1.0086	1.2607	1.5128
CT3	1.08	1.08	.9975	.1995	.2494	.2992
Slope D						
C1	190.5	238.125	219.9299	43.9860	54.9825	65.9790
C2	167.28	209.1	193.1227	38.6245	48.2807	57.9368
C3	33.48	41.85	38.6522	7.7304	9.6630	11.5957
CT1	14.22	14.22	13.1338	2.6267	3.2834	3.9400
CT2	12.48	12.48	11.5264	2.3053	2.8816	3.4579
CT3	2.52	2.52	2.3274	.4655	.5819	.6982

[a]From Table B.1.

[b]Source: [72].

[c]Conversion factor from tons per acre to milligrams per liter in Nishnabotna River Basin is .92359 [104].

Table B.6 (Continued)

	Rotation Soil Loss[a]	Include Gully Erosion[b]	Sediment Conversion[c]	Sediment Load DR=.20	Sediment Load DR=.25	Sediment Load DR=.30
	tons/acre			10^3 mg/liter		
Slope E						
C1	370.59	463.2375	427.8415	85.5683	106.9604	128.3525
C2	325.38	406.725	375.6471	75.1294	93.9118	112.6941
C3	65.1	81.375	75.1571	15.0314	18.7893	22.5471
CT1	25.8	25.8	23.8286	4.7657	5.9572	7.1486
CT2	22.62	22.62	20.8916	4.1783	5.2229	6.2675
CT3	4.5	4.5	4.1562	.8312	1.039	1.2468

Table B.7. Soil loss and sediment concentration - spring-plow

	Rotation Soil Loss[a]	Include Gully Erosion[b]	Sediment Conversion[c]	Sediment Load DR=.20	DR=.25	DR=.30
	tons/acre			10^3 mg/liter		
Slope A						
S1	12.42	15.525	14.3387	2.8677	3.5847	4.3016
S2	11.04	13.8	12.7455	2.5491	3.1864	3.8237
S3	2.22	2.775	2.5630	.5126	.6407	.7689
SC1	7.44	9.3	8.5894	1.7179	2.1473	2.5768
SC2	6.60	8.25	7.6196	1.5239	1.9049	2.2859
SC3	1.32	1.65	1.5239	.3048	.3810	.4572
Slope B						
S1	31.5	39.48	36.3664	7.2733	9.0916	10.9100
S2	28.02	35.025	32.3487	6.4697	8.0872	9.7046
S3	5.58	6.975	6.4420	1.2884	1.6105	1.9326
SC1	15.75	19.6875	18.1832	3.6366	4.5458	5.4550
SC2	13.98	17.475	16.1397	3.2279	4.0349	4.8419
SC3	2.87	3.525	3.2557	.6511	.8139	.9767
ST1	2.64	2.64	2.4383	.4877	.6096	.7315
ST2	2.34	2.34	2.1612	.4322	.5403	.6484
ST3	.48	.48	.4488	.0887	.1108	.1330
Slope C						
S1	82.29	102.8625	95.0028	19.0006	23.7507	28.5008
S2	73.14	91.425	84.4392	16.8878	21.1098	25.3318
S3	14.64	18.3	16.9017	3.66	4.575	5.49
ST1	5.49	5.49	5.0705	1.0141	1.2676	1.5211
ST2	4.86	4.86	4.4886	.8977	1.1222	1.3466
ST3	.96	.96	.8866	.1773	.2217	.2660
Slope D						
S1	167.25	209.0625	193.0880	38.6176	48.2720	57.9264
S2	148.68	185.85	171.6492	34.3298	42.9123	51.4948
S3	29.76	37.2	34.3575	6.8715	8.5894	10.3073
ST1	12.48	12.48	11.5264	2.3053	2.8816	3.4579
ST2	11.1	11.1	10.2518	2.0504	2.5630	3.0756
ST3	2.22	2.22	2.0504	.4101	.5126	.6151

[a]From Table B.1.

[b]Source: [72].

[c]Conversion factor from tons per acre to milligrams per liter in Nishnabotna River Basin is .92359 [104].

Table B.7 (Continued)

	Rotation Soil Loss[a]	Include Gully Erosion[b]	Sediment Conversion[c]	Sediment Load DR=.20	DR=.25	DR=.30
	tons/acre			10^{-3} mg/liter		
Slope E						
S1	325.41	406.7625	375.6817	75.1364	93.9204	112.7045
S2	289.26	361.575	333.9471	66.7894	83.4868	100.1841
S3	57.84	72.3	66.7756	13.3551	16.6939	20.0327
ST1	22.65	22.65	20.9193	4.1839	5.2298	6.2758
ST2	20.1	20.1	18.5642	3.7128	4.6410	5.5692
ST3	4.02	4.02	3.7128	.7426	.9282	1.1138

Table B.8. Soil loss and sediment concentration - minimum tillage, meadow and permanent pasture

	Rotation Soil Loss[a]	Include Gully Erosion[b]	Sediment Conversion[c]	Sediment Load		
				DR=.20	DR=.25	DR=.30
	tons/acre			10^{-3} mg/liter		
Slope A						
M1	6.9	8.625	7.9660	1.5932	1.9915	2.3898
M2	7.56	9.45	8.7279	1.7456	2.1820	2.6184
MC1	2.82	3.53	3.2557	.6511	.8139	.9767
MC2	3.12	3.9	3.6020	.7204	.9005	1.0806
H	.66	.66	.6096	.1219	.1524	.1829
Slope B						
M1	17.52	21.9	20.2266	4.0453	5.0567	6.0680
M2	19.26	24.075	22.2354	4.4471	5.5589	6.6706
MC1	5.25	6.5625	6.0611	1.2122	1.5153	1.818
MC2	5.76	7.2	6.6498	1.330	1.662	1.9950
H	1.74	1.74	1.6070	.3214	.4018	.4821
Slope C						
M1	45.72	57.15	52.7832	10.5566	13.1958	15.8350
M2	50.28	62.85	58.0476	11.6095	14.5119	17.4143
MC1	15.99	19.9875	18.4603	3.6921	4.6151	5.5381
MC2	17.58	21.975	16.2367	3.2473	4.0592	4.8710
MT1	3.36	3.36	3.1033	.6207	.7758	.9310
MT2	3.72	5.72	3.4358	.6872	.8589	1.0307
H	4.56	4.56	4.2115	.8423	1.0529	1.2635
Slope D						
M1	92.91	116.1375	107.2634	21.4527	26.8159	32.1790
M2	102.24	127.8	118.0348	23.6070	29.5087	35.4104
MT1	6.93	6.93	6.4005	1.2801	1.6001	1.9201
MT2	7.62	7.62	7.0378	1.4076	1.7594	2.1113
H	9.24	9.24	8.5340	1.7068	2.1335	2.5602

[a]From Table B.1.

[b]Source: [72].

[c]Conversion factor from tons per acre to milligrams per liter in Nishnabotna River Basin is .92359 [104].

Table B.8 (Continued)

	Rotation Soil Loss[a]	Include Gully Erosion[b]	Sediment Conversion[c]	Sediment Load DR=.20	Sediment Load DR=.25	Sediment Load DR=.30
	tons/acre			10^{-3} mg/liter		
Slope E						
M1	180.78	225.975	208.7083	41.7417	52.1771	62.6125
M2	198.84	248.55	229.5583	45.9117	57.3896	68.8675
MT1	12.57	12.57	11.6095	2.3219	2.9024	3.4829
MT2	13.86	13.86	12.8010	2.5602	3.2002	3.8403
H	18.06	18.06	16.6800	3.3360	4.1700	5.0040
Permanent Pasture						
F	3.15	3.15	2.9093	.5819	.7273	.8728
G	5.56	5.56	5.1352	1.0270	1.2838	1.5405
AP	.05	.05	.0462	.0092	.0115	.0139
BP	.12	.12	.1108	.0222	.0277	.0332
CP	.30	.30	.2771	.0554	.0693	.0831
DP	.62	.62	.5726	.1145	.1432	.1718
EP	1.20	1.20	1.1083	.2217	.2771	.3325

Table B.9. Crop yields[a]

	Land Class[b]				
	A[c]	B	C	D	E
Contil Fall-Plow					
Corn	109	107	99	90	69
Soybeans	41	41	38	34	26
Oats	62	61	56	51	39
Hay	4.1	4.0	3.8	3.4	2.6
Contil Contour Fall-Plow					
Corn	109	109	X	X	X
Soybeans	41	41	X	X	X
Oats	62	62	X	X	X
Hay	4.1	4.0	X	X	X
Contil Terrace Fall-Plow[d]					
Corn	X	106	97	87	60
Soybeans	X	40	37	32	23
Oats	X	60	54	49	34
Hay	X	4.0	3.7	3.2	2.3
Contil Spring-Plow					
Corn	101	99	92	84	64
Soybeans	41	41	38	34	26
Oats	62	61	56	51	39
Hay	4.1	4.0	3.8	3.4	2.6
Contil Contour Spring-Plow					
Corn	101	101	X	X	X
Soybeans	41	41	X	X	X
Oats	62	62	X	X	X
Hay	4.1	4.0	X	X	X

[a] All yields in bushels per acre except hay which is reported in tons per acre. Sources: [1, 3, 28, 37, 75, 79, 82].

[b] The mark X indicates crop activity is not allowed on a land class because of ineffectiveness of conservation practice.

[c] Applies to slope A1 and slope A.

[d] Per acre yield based on total terraced area including grassed backslope.

Table B.9 (Continued)

	Land Class[b]				
	A[c]	B	C	D	E
Contil Terrace Spring-Plow[d]					
Corn	X	98	90	81	56
Soybeans	X	40	37	32	23
Oats	X	60	54	49	34
Hay	X	4.0	3.7	3.2	2.3
Mintil					
Corn	105	103	95	86	66
Soybeans	41	41	38	34	26
Oats	62	61	56	51	39
Hay	4.1	4.0	3.8	3.4	2.6
Mintil Contour					
Corn	105	105	101	X	X
Soybeans	41	41	40	X	X
Oats	62	62	59	X	X
Hay	4.1	4.0	3.8	X	X
Mintil Terrace[d]					
Corn	X	X	94	84	58
Soybeans	X	X	37	32	23
Oats	X	X	55	49	34
Hay	X	X	3.7	3.2	2.3

Table B.10. Land distribution by land class in Nishnabotna River Basin[a]

Land Class	Acreage	Slope Gradient (%)	Average Slope Gradient (%)	Average Slope Length (feet)	Erosion Hazard[b]
Tilled land					
A1	212,062	Level land,	nonerodible		None
A	30,116	less than 2	1	247	Slight
B	445,898	2-4.9	3	324	Slight
C	194,375	5-8.9	7	303	Moderate
D	513,143	9-13.9	11	337	Severe
E	75,052	14-17.9	16	386	Severe
Pasture land[c]					
F	20,123	18-24.9	22	399	Severe
G	4,360	25 and over	30	415	Severe
AP[d]	18,808	less than 2	1	247	Slight
BP	60,497	2-4.9	3	324	Slight
CP	17,968	5-8.9	7	303	Moderate
DP	37,840	9-13.9	11	337	Severe
EP	19,464	14-17.9	16	386	Severe
Total	1,649,706				

[a]Sources used in developing this table: USDA computer tape derived from 1967 CNI for Iowa (USDA collaborator, Iowa State University); Land Use Table, Final from Southern Iowa Rivers Basin Study, table dated January 4, 1977; 1975 Potential Cropland Study by USDA-SCS, mimeo. July, 1976 [99].

[b]Source: [100].

[c]Cannot be tilled without development such as access road, gully control, or drain tile, etc.

[d]Includes A land but predominantly A1.

APPENDIX C

Table C.1. Policy simulation results: normal price-relative

Policy Simulation	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/acre	Sediment Load		
							Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
	A1	A	B	C	D	E	1000 bushels			1000 tons			mg/liter		
1. Base run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	27,860	20.3	7,720	9,650	11,580
2. Ban on fall-plow	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	27,240	10.0	3,810	4,760	5,710
3. Ban on fall-plow and straight-row plow	M1	M1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	25,880	2.1	720	900	1,070
4. Ban on straight-row plow	C1	C1	CC1	MC1	CT1/C3	H	89,995	16,761	1052	313	26,380	4.1	1,430	1,790	2,150
5. Soil loss limit	C1	C1	MC1	MC2/MT1	CT/1	H	87,309	16,601	1656	313	25,210	2.5	810	1,010	1,220
6. Contour subsidy 60¢	C1	CC1	CC1	MC1	C1/H	H	90,690	17,209	939	313	27,937	20.2	7,700	9,630	11,550

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.2. Policy simulation results: high price-relative

Policy Simulation	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/acre	Sediment Load		
							Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
	A1	A	B	C	D	E	1000 bushels			1000 tons			mg/liter		
1. Base run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	47,700	20.3	7,720	9,650	11,580
2. Ban on fall-plow	M1	M1	MC1	MC1	M1/H	H	87,628		939	313	46,620	10.0	3,810	4,760	5,710
3. Ban on fall-plow and straight-row plow	M1	M1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	45,060	2.1	720	900	1,070
4. Ban on straight-row plow	C1	C1	CC1	MC1	CT1/C3	H	89,995	16,761	1052	313	45,980	4.1	1,430	1,790	2,150
5. Soil loss limit	C1	C1	MC1	CT1	CT1/H	H	88,062	17,209	939	313	44,440	2.4	770	970	1,160
6. Contour subsidy 60¢	C1	CC1	CC1	MC1	C1/H	H	90,690		939	313	47,773	20.2	7,700	9,630	11,550

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.3. Policy simulation results: low price-relative

Policy Simulation	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/acre	Sediment Load		
							Corn	Soybeans	Oats	Hay			DR=.20	DR=.25	DR=.30
	A1	A	B	C	D	E	1000 bushels			1000 tons			mg/liter		
1. Base run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	17,080	20.3	7,720	9,650	11,580
2. Ban on fall-plow	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	16,710	10.0	3,810	4,760	5,710
3. Ban on fall-plow and straight-row plow	M1	M1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	15,450	1.1	720	900	1,070
4. Ban on straight-row plow	C1	C1	CC1	MC1	CT1/H	H	89,995	16,761	1052	313	15,740	4.1	1,430	1,790	2,150
5. Soil loss limit	C1	C1	MC1	MC2/MT1	CT1	H	87,309	16,601	1656	313	14,780	2.5	810	1,010	1,220
6. Contour subsidy 60¢	C1	CC1	CC1	MC1	C1/H	H	90,690	17,209	939	313	17,156	20.2	7,700	9,630	11,550

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.4. Soil loss tax simulation results: normal price-relative

Tax Level Per Ton of Soil Loss Per Year	Choice of Technology and Land Use[a]						Production				Net farm Income	Average Soil Loss Tons/Acre	Sediment Load		
							Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
	A1	A	B	C	D	E	1000 bushels			1000 tons			mg/liter		
1. Base Run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	27,860	20.3	7,720	9,650	11,580
2. $.10	C1	C1	CC1	MC1	M1/H	H	89,463	17,209	939	313	27,250	11.2	4,260	5,330	6,390
3. .20	C1	C1	CC1	MC1	M1/H	H	89,463	17,209	939	313	26,890	11.2	4,260	5,330	6,390
4. .30	C1	CC1	CC1	MC1	M1/H	H	89,463	17,209	939	313	26,530	11.2	4,250	5,310	6,370
5. .40	C1	CC1	CC1	MC1	M1/H	H	89,463	17,209	939	313	26,170	11.2	4,250	5,310	6,370
6. .50	C1	CC1	CC1	MC1	M1/H	H	89,463	17,209	939	313	25,820	11.2	4,250	5,310	6,370
7. 1.00	C1	CC1	MC1	MC1	MT1/H	H	87,660	16,902	939	313	25,350	2.1	720	900	1,080
8. 1.50	C1	MC1	MC1	MC1	MT1/H	H	87,580	16,902	939	313	25,020	2.0	710	880	1,060
9. 2.00	C1	MC1	MC1	MC1	MT1/H	H	87,580	16,902	939	313	24,690	2.0	710	880	1,060
10. 2.50	C1	MC1	MC1	MC1	MT1/H	H	87,580	16,902	939	313	24,360	2.0	710	880	1,060
11. 3.00	C1	MC1	MC1	MC1	MT1/H	H	87,580	16,902	939	313	24,040	2.0	710	880	1,060
12. 3.50	C1	MC1	MC1	MC1	MT1/H	H	87,580	16,902	939	313	23,720	2.0	710	880	1,060
13. 4.00	C1	MC1	MC1	MC1	MT1/H	H	87,580	16,902	939	313	23,390	2.0	710	880	1,060

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.5. Soil loss tax simulation results: high price-relative

Tax Level Per Ton of Soil Loss Per Year	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/ Acre	Sediment Load		
	Al	A	B	C	D	E	Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
							1000 bushels			1000 tons			mg/liter		
1. Base Run	Cl	Cl	CCl	MCl	Cl/H	H	90,690	17,209	939	313	47,700	20.3	7,720	9,650	11,580
2. $.10	Cl	Cl	CCl	MCl	Cl/H	H	90,690	17,209	939	313	47,050	20.3	7,720	9,650	11,580
3. .20	Cl	Cl	CCl	MCl	Ml/H	H	89,463	12,209	939	313	46,550	11.2	4,260	5,330	6,390
4. .30	Cl	CCl	CCl	MCl	Ml/H	H	89,463	12,209	939	313	46,190	11.2	4,250	5,310	6,370
5. .40	Cl	CCl	CCl	MCl	Ml/H	H	89,463	12,209	939	313	45,830	11.2	4,250	5,310	6,370
6. .50	Cl	CCl	CCl	MCl	Ml/H	H	89,463	12,209	939	313	45,470	11.2	4,250	5,310	6,370
7. 1.00	Cl	CCl	CCl	MCl	CTl/H	H	89,770	16,902	939	313	44,730	3.9	1,360	1,700	2,040
8. 1.50	Cl	CCl	MCl	MCl	MTl/H	H	87,660	16,902	939	313	44,300	2.1	720	900	1,080
9. 2.00	Cl	CCl	MCl	MCl	MTl/H	H	87,660	16,902	939	313	43,970	2.1	720	900	1,080
10. 2.50	Cl	CCl	MCl	MCl	MTl/H	H	87,660	16,902	939	313	43,640	2.1	720	900	1,080
11. 3.00	Cl	MCl	MCl	MCl	MTl/H	H	87,580	16,902	939	313	43,310	2.0	710	880	1,060
12. 3.50	Cl	MCl	MCl	MCl	MTl/H	H	87,580	16,902	939	313	42,990	2.0	710	880	1,060
13. 4.00	Cl	MCl	MCl	MCl	MTl/H	H	87,580	16,902	939	313	42,670	2.0	710	880	1,060

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.6. Soil loss tax simulation results: low price-relative

Tax Level Per Ton of Soil Loss Per Year	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/ Acre	Sediment Load		
	A1	A	B	C	D	E	Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
							1,000 bushels			1000 tons			mg/liter		
1. Base Run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	17,080	20.3	7,720	9,650	11,580
2. $.10	C1	C1	CC1	MC1	M1/H	H	89,463	17,209	939	313	16,570	11.2	4,260	5,330	6,390
3. .20	C1	C1	CC1	MC1	M1/H	H	89,463	17,209	939	313	16,210	11.2	4,260	5,330	6,390
4. .30	C1	CC1	CC1	MC1	M1/H	H	89,463	17,209	939	313	15,850	11.2	4,250	5,310	6,370
5. .40	C1	CC1	MC1	MC1	M1/H	H	88,274	17,209	939	313	15,500	10.1	3,810	4,770	5,724
6. .50	C1	CC1	MC1	MC1	MT1/H	H	87,660	16,902	939	313	15,200	2.1	720	900	1,080
7. 1.00	C1	MC1	MC1	MC1	MT1/H	H	87,580	16,902	939	313	14,870	2.0	710	880	1,060
8. 1.50	C1	MC1	MC1	MC1	MT1/H	-	84,366	16,290	939	313	14,560	1.9	660	820	980
9. 2.00	C1	MC1	MC1	MC1	MT1/H	-	84,366	16,290	939	313	14,260	1.9	660	820	980
10. 2.50	C1	MC1	MC1	MC1	MT1/H	-	84,366	16,290	939	313	13,960	1.9	660	820	980
11. 3.00	C1	MC1	MC1	MC1	MT1/H	-	84,366	16,290	939	313	13,660	1.9	660	820	980
12. 3.50	C1	MC1	MC1	MC1	MT1/H	-	84,366	16,290	939	313	13,360	1.9	660	820	980
13. 4.00	C1	MC1	MC1	MC1	MT1/H	-	84,366	16,290	939	313	13,060	1.9	660	820	980

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.7. Soil loss tax and ban on fall-plow simulation results: normal price-relative

Tax Level Per Ton of Soil Loss Per Year	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/ Acre	Sediment Load		
	A1	A	B	C	D	E	Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
							1000 bushels			1000 tons			mg/liter		
1. Base Run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	27,860	20.3	7,720	9,650	11,580
2. Ban fall-plow	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	27,240	10.0	3,810	4,760	5,710
3. $.10	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	26,920	10.0	3,810	4,760	5,710
4. .20	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	26,600	10.0	3,810	4,760	5,710
5. .30	M1	MC1	MC1	MC1	M1/H	H	87,628	17,209	939	313	26,280	10.0	3,800	4,750	5,700
6. .40	M1	MC1	MC1	MC1	M1/H	H	87,628	17,209	939	313	25,960	10.0	3,800	4,750	5,700
7. .50	M1	MC1	MC1	MC1	M1/H	H	87,628	17,209	939	313	25,640	10.0	3,800	4,750	5,700
8. 1.00	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	25,220	2.0	710	880	1,060
9. 1.50	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	24,900	2.0	710	880	1,060
10. 2.00	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	24,570	2.0	710	880	1,060
11. 2.50	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	24,240	2.0	710	880	1,060
12. 3.00	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	23,920	2.0	710	880	1,060
13. 3.50	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	23,600	2.0	710	880	1,060
14. 4.00	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	23,270	2.0	710	880	1,060

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.8. Soil loss tax and ban on fall-plow simulation results: high price-relative

Tax Level Per Ton of Soil Loss Per Year	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/Acre	Sediment Load		
	Al	A	B	C	D	E	Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
							1000 bushels			1000 tons			mg/liter		
1. Base Run	Cl	Cl	CCl	MCl	Cl/H	H	90,690	17,209	939	313	47,700	20.3	7,720	9,650	11,580
2. Ban fall-plow	Ml	Ml	MCl	MCl	Ml/H	H	87,628	17,209	939	313	46,620	10.0	3,810	4,760	5,710
3. $.10	Ml	Ml	MCl	MCl	Ml/H	H	87,628	17,209	939	313	46,300	10.0	3,810	4,760	5,710
4. .20	Ml	Ml	MCl	MCl	Ml/H	H	87,628	17,209	939	313	45,980	10.0	3,810	4,760	5,710
5. .30	Ml	MCl	MCl	MCl	Ml/H	H	87,628	17,209	939	313	45,660	10.0	3,800	4,750	5,700
6. .40	Ml	MCl	MCl	MCl	Ml/H	H	87,628	17,209	939	313	45,330	10.0	3,800	4,750	5,700
7. .50	Ml	MCl	MCl	MCl	Ml/H	H	87,628	17,209	939	313	45,000	10.0	3,800	4,750	5,700
8. 1.00	Ml	MCl	MCl	MCl	MTl/H	H	87,015	16,902	939	313	44,410	2.0	710	880	1,060
9. 1.50	Ml	MCl	MCl	MCl	MTl/H	H	87,015	16,902	939	313	44,080	2.0	710	880	1,060
10. 2.00	Ml	MCl	MCl	MCl	MTl/H	H	87,015	16,902	939	313	43,760	2.0	710	880	1,060
11. 2.50	Ml	MCl	MCl	MCl	MTl/H	H	87,015	16,902	939	313	43,430	2.0	710	880	1,060
12. 3.00	Ml	MCl	MCl	MCl	MTl/H	H	87,015	16,902	939	313	43,110	2.0	710	880	1,060
13. 3.50	Ml	MCl	MCl	MCl	MTl/H	H	87,015	16,902	939	313	42,780	2.0	710	880	1,060
14. 4.00	Ml	MCl	MCl	MCl	MTl/H	H	87,015	16,902	939	313	42,460	2.0	710	880	1,060

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.9. Soil loss tax and ban on fall-plow simulation results: low price-relative

Tax Level Per Ton of Soil Loss Per Year	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/Acre	Sediment Load		
							Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
	A1	A	B	C	D	E	1000 bushels			1000 tons			mg/liter		
1. Base Run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	17,080	20.3	7,720	9,650	11,580
2. Ban fall-plow	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	16,710	10.0	3,810	4,760	5,710
3. $.10	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	16,390	10.0	3,810	4,760	5,710
4. .20	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	16,070	10.0	3,810	4,760	5,710
5. .30	M1	MC1	MC1	MC1	M1/H	H	87,628	17,209	939	313	15,750	10.0	3,800	4,750	5,700
6. .40	M1	MC1	MC1	MC1	M1/H	H	87,628	17,209	939	313	15,420	10.0	3,800	4,750	5,700
7. .50	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	15,120	2.0	710	880	1,060
8. 1.00	M1	MC1	MC1	MC1	MT1/H	H	87,015	16,902	939	313	14,700	2.0	710	880	1,060
9. 1.50	M1	MC1	MC1	MC1	MT1/H	-	83,801	16,290	939	313	14,480	1.9	660	820	980
10. 2.00	M1	MC1	MC1	MC1	MT1/H	-	83,801	16,290	939	313	14,180	1.9	660	820	980
11. 2.50	M1	MC1	MC1	MC1	MT1/H	-	83,801	16,290	939	313	13,880	1.9	660	820	980
12. 3.00	M1	MC1	MC1	MC1	MT1/H	-	83,801	16,290	939	313	13,590	1.9	660	820	980
13. 3.50	M1	MC1	MC1	MC1	MT1/H	-	83,801	16,290	939	313	13,290	1.9	660	820	980
14. 4.00	M1	MC1	MC1	MC1	MT1/H	-	83,801	16,290	939	313	12,990	1.9	660	820	980

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.10. Mintil subsidy simulation results: normal price-relative

Subsidy Level Per Acre	Choice of Technology and Land Use[a]						Production			Hay	Net Farm Income	Average Soil Loss Tons/ Acre	Sediment Load		
	A1	A	B	C	D	E	Corn	Soy-beans	Oats	1,000 tons			DR=.20	DR=.25	DR=.30
							1,000 bushels						mg/liter		
1. Base Run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	27,860	20.3	7,720	9,650	11,580
2. $2.50	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	27,960	20.3	7,720	9,650	11,580
3. 2.60	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	27,960	20.3	7,720	9,650	11,580
4. 2.70	C1	C1	MC1	MC1	C1/H	H	89,501	17,209	939	313	27,970	19.2	7,280	9,100	10,920
5. 2.80	C1	C1	MC1	MC1	C1/H	H	89,501	17,209	939	313	27,980	19.2	7,280	9,100	10,920
6. 2.90	C1	C1	MC1	MC1	M1/H	H	88,274	17,209	939	313	28,000	10.1	3,830	4,780	5,740
7. 3.00	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	28,020	10.0	3,810	4,760	5,710

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.11. Mintil subsidy simulation results: high price-relative

Subsidy Level Per Acre	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/Acre	Sediment Load		
	A1	A	B	C	D	E	Corn	Soy-beans	Oats	Hay			DR=.20	DR=.25	DR=.30
							1000 bushels			1000 tons			mg/liter		
1. Base Run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	47,700	20.3	7,720	9,650	11,580
2. $4.50	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	47,870	20.3	7,720	9,650	11,580
3. 4.60	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	47,870	20.3	7,720	9,650	11,580
4. 4.70	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	47,880	20.3	7,720	9,650	11,580
5. 4.80	C1	C1	MC1	MC1	C1/H	H	89,501	17,209	939	313	47,880	12.9	7,280	9,100	10,920
6. 4.90	C1	C1	MC1	MC1	M1/H	H	88,274	17,209	939	313	47,900	10.1	3,830	4,780	5,740
7. 5.00	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	47,920	10.05	3,810	4,760	5,710

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.

Table C.12. Mintil subsidy simulation results: low price-relative

Subsidy Level Per Acre	Choice of Technology and Land Use[a]						Production				Net Farm Income	Average Soil Loss Tons/ Acre	Sediment Load		
	A1	A	B	C	D	E	Corn	Soy- beans	Oats	Hay			DR=.20	DR=.25	DR=.30
							1000 bushels			1000 tons			mg/liter		
1. Base Run	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	17,080	20.3	7,720	9,65	11,580
2. $1.50	C1	C1	CC1	MC1	C1/H	H	90,690	17,209	939	313	17,140	20.3	7,720	9,650	11,580
3. 1.60	C1	C1	MC1	MC1	M1/H	H	89,501	17,209	939	313	17,140	19.2	7,280	9,100	10,920
4. 1.70	C1	C1	MC1	MC1	M1/H	H	88,274	17,209	939	313	17,160	10.1	3,830	4,780	5,740
5. 1.80	C1	C1	MC1	MC1	M1/H	H	88,274	17,209	939	313	17,180	10.1	3,830	4,780	5,740
6. 1.90	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	17,200	10.0	3,810	4,760	5,710
7. 2.00	M1	M1	MC1	MC1	M1/H	H	87,628	17,209	939	313	17,230	10.0	3,810	4,760	5,710

[a]The following land classes were in permanent pasture; F, G, AP, BP, CP, DP, EP. The legend for crop activity names appears in Figure 4.1.